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CHEMICAL COMPOSITION, DIGESTIBILITY, AND FEEDING VALUE OF VEGETABLE-IVORY MEAL[1]

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INTRODUCTION

Vegetable ivory, or the corozo nut, as it is commonly known in commerce, is the seed or nut of the palmlike plant *Phytelephas macrocarpa*. It is a native of the Latin American countries, being found in great quantities along the banks of the Magdalena, in Colombia, where it is known as "tagua." It is also found in Peru and in the forests of northern Ecuador. In appearance the plant itself is a stemless palm, bearing its fruit in conglomerate heads, often weighing 25 to 30 pounds apiece. These heads are made up of 30 to 50 seeds or nuts, varying in size from half an inch to several inches in diameter. In the earlier stages of growth the seed contains a clear, insipid liquid, which later changes to a sweet, milky paste, and finally hardens into the white horny substance from which it derives its name "vegetable ivory."

Large quantities of the nuts are imported annually by Great Britain and Germany, principally for the manufacture of buttons. The United States uses about 10,000 tons annually, costing $1,500,000 (1, p. 200).[2] Beneath the brown outer coating the dried nut has the appearance of dentine ivory, and can easily be sawed, carved, and turned into all sizes and shapes of buttons, while the texture is such that it readily absorbs dyes and will take a high polish.

In the process of manufacture a considerable portion of the nut is wasted in the form of sawdust, chips, and turnings. In foreign countries this waste has been mixed with other ingredients to be used as a cattle food. German writers state that vegetable-ivory meal has been used

[1] From the Department of Chemistry, Massachusetts Agricultural Experiment Station. Printed with the permission of the Director of the Station.

[2] Reference is made by number to "Literature cited," p. 320.

as an adulterant in the manufacture of so-called concentrated feeds. Some instances are given where as much as 50 per cent of this material has been added.

In the last few years considerable attention has been attracted in this country to the enormous amount of waste material produced by ivory-button factories, and many attempts have been made to discover a practical use for the material aside from fuel.

The material experimented with had the appearance of a medium-fine meal, white in color, though flecked here and there with particles of the brown outer coating of the nut. It was tasteless, odorless, and very hard, being almost gritty to the touch.

CHEMICAL COMPOSITION OF VEGETABLE-IVORY MEAL

Considerable work has been done on the chemistry of vegetable ivory both in this country and in Europe. Tollens (14, p. 113), Fischer and Hirschberger (7), Liebscher (11), and others have worked with ivory meal as a source of mannose and have otherwise investigated the material.

A considerable amount of corroborative chemical investigation of vegetable ivory has been undertaken and an attempt made to determine quantitatively the mannose present. The results are presented with as little detail as possible, the fodder analyses being given in Table I.

TABLE I.—*Fodder analyses of vegetable ivory*

Constituent.	Maximum.	Minimum.	Average.[a]	German analyses for comparison.
Moisture	12.64	6.13	11.39	18.30–13.20
Ash	2.30	.80	1.08	1.30– 1.10
Protein	5.26	3.94	4.63	4.60– 4.00
Fat	1.18	.60	.92	1.10– 0.80
Fiber	7.75	6.13	6.89	79.80–75.80
Nitrogen-free extract	77.56	74.17	75.09	

[a] Average of nine samples.

At a glance Table I shows not only the variations met with in different samples but that by far the greater part of the material is carbohydrate in nature. The protein rarely exceeds 5 per cent and was found to contain about one-third of its nitrogen in the amido form. The fat or ether extract had the appearance of a heavy light-colored oil and possessed a pleasant nutty odor.

The fiber in all cases was fairly uniform in amount, being about 7 per cent of the dry matter. It was noticed while making the determinations that the vegetable ivory acted as an indicator, the change from light buff with acid to a deep wine color with alkali being quite abrupt. Both the residue from the fiber determinations and the original material were

tested for the presence of lignin, but neither phloroglucinol nor anilin sulphate produced any color reaction whatever. As three-fourths of the vegetable ivory was found to be nitrogen-free extract, it was to this portion that the most attention was given.

It has long been known that the greater part of the carbohydrate material consists of mannose, or, more accurately speaking, mannan, its anhydrid condensation product.

The isolation of mannose was carried out practically as described by Fischer and Hirschberger (7). One hundred gm. of vegetable-ivory meal were digested on the water bath with reflux condenser for six hours with 200 c. c. of 6 per cent hydrochloric acid. The liquid was then filtered off, the filtrate and washings neutralized with sodium hydroxid, and shaken out several times with carbon black. After filtration, phenylhydrazin (dissolved in acetic acid) was added at the rate of 0.3 gm. for every gram of ivory meal used. The mannose phenylhydrazone separated out on standing for 24 hours in the cold as a heavy, fine-grained, buff-colored precipitate. This was washed with cold water and dried in a vacuum at room temperature. Particles of this impure hydrazone when placed in a capillary tube and heated slowly in a sulphuric-acid bath melted at 183° C.

A portion of the precipitate was purified by boiling for a long time with a large volume of 95 per cent alcohol, filtering, and again boiling with fresh alcohol until at the end of two days an almost snow-white hydrazone resulted. This melted at 196° C., demonstrating the existence of mannose or its polymer mannan in vegetable ivory.

To liberate mannose from its phenylhydrazone, a portion of the latter was digested with benzaldehyde and alcohol until crystals of benzaldehyde hydrazone formed. The mannose containing filtrate from these, after clarifying and evaporating to a sirup, was treated with absolute alcohol and set aside to crystallize. The mannose crystals obtained had a melting point of 132° C.

Pentosans were determined by the hydrochloric-acid distillation method and precipitation with phloroglucinol. The average of three determinations was 2.43 per cent of the dry matter.

Repeated attempts to produce mucic acid by oxidation with nitric acid proved futile. The exact method for the detection and determination of galactan was carried out always with negative results.

Microscopic examination with iodin failed to give the slightest evidence of starch, either in the white fleshy part of the nut or in the brown outer coating.

Dextrose (or dextran) was shown to be absent in vegetable ivory by its inability to form saccharic acid. As a check on the method used, a sample of pure glucose was treated exactly as was the ivory meal. No difficulty was experienced in obtaining the saccharic acid from the check.

It was found by boiling a little of the vegetable-ivory meal in water, filtering out the insoluble portion, and then adding the clear filtrate to a large volume of strong alcohol that a precipitate would form after standing for some time. Since this process is similar to that employed in separating pectin (plant mucilage) from fruits, it was first supposed to be the same product. The amount present was found to be 2.78 per cent on a dry-matter basis.

According to the best authorities, pectin, supposed by many to be an oxygen or acid derivative of cellulose, is readily oxidized to mucic acid by proper treatment with nitric acid. The product from vegetable-ivory meal when so treated produced no mucic acid. That it could not be of pentose character was demonstrated by making determinations on the filtered precipitate. Not the slightest trace of phloroglucid formed, showing the absence of five carbon sugars.

From various authorities and from actual observation, pectin derived from fruit is known to reduce Fehling's solution. Indications of such reduction were not noted in the case of this precipitate.

On the supposition that it might be of a nitrogenous nature, a nitrogen determination was made with negative results.

Considering these results, it would seem that the alcoholic precipitate from vegetable-ivory meal is distinctly different from the so-called "plant mucilage."

In attempting the determination of the sugars present in vegetable-ivory meal by Fehling's gravimetric method, many difficulties were encountered. However, a brief summary of the results obtained seems worthy of note. Water extracts of the material without inversion gave about 0.5 per cent of reducing material. The same solution after hydrolysis with hydrochloric acid at 20° C. for 24 hours gave an average of 2 per cent of reducing material. From this it was evident that the mannose, or, more properly speaking, the mannan, existed as a hemicellulose, since otherwise the total sugars would have been in an enormous excess of 2 per cent. Consequently the hydrolysis was made more drastic by boiling, and it was found that with an increase in the length of the boiling period the percentages of sugars increased (Table II).

TABLE II.—*Relation of the length of the boiling period to the percentage of sugars in vegetable-ivory meal*

Hours boiled.	Percentage of sugar (as dextrose).
2½	47.40
4	65.00
5	73.40
6	73.40
7	73.40

It was noticed that five hours' boiling in an acid solution was necessary to hydrolyze completely the mannose and other reducing materials and that more than five hours' boiling produced no increased percentage.

The percentages were calculated not as mannose but as dextrose, since no table for the determination of mannose by Fehling's method has been found.

The pentosans present no doubt had a somewhat different reducing capacity than the mannan. However, when appropriate allowance had been made for moisture and pectin (previously determined), the total carbohydrates estimated in this fashion approached to within less than 1 per cent of the amount estimated as nitrogen-free extract in the original fodder analysis. It is evident, therefore, that the so-called nitrogen-free extract, comprising fully 75 per cent of the vegetable-ivory meal, was composed principally of mannan with small amounts of pentosans and of a substance insoluble in alcohol but not identical with the pectin substances as usually found in plants.

CALORIFIC VALUE OF VEGETABLE-IVORY MEAL

To determine the calorific value of this substance a number of bomb-calorimeter determinations were made, the average of which is given in Table III, together with representative figures for other common substances used as food.

TABLE III.—*Comparative calorific values of vegetable-ivory meal, corn meal, sugar, and cornstarch*

Material.	Small calories, per gram.	Large calories, per pound.
Vegetable-ivory meal	3,785	1,717
Corn meal (9, p. 405, 420)[1]	3,549	1,610
Sugar (guaranteed)	3,958	1,753
Cornstarch (9, p. 405, 420)	3,692	1,675

[1] H. P. Armsby (2, p. 13) reports corn meal as having a chemical energy of 170.9 therms per 100 pounds, the equivalent of 3,766 small calories per gram, or 1,709 large calories per pound.

In button factories, where the largest amount of ivory waste, or meal, is produced, the material is used under the boilers as fuel, and it has been authoritatively stated[1] that it produces about half as much heat as coal. It is interesting to note how accurately this statement is borne out scientifically. The average of 20 samples of soft coal recently analyzed at this station was 14,074 B. T. U., which, expressed in large calories per pound, equals 3,546. This figure is approximately twice that of the vegetable-ivory meal, 1,717.

[1] Courtesy of Mr. C. J. Spill, Superintendent of the United Button Co., Springfield, Mass.

DIGESTION EXPERIMENTS

EXPERIMENT I.—The determination of digestibility was carried out with two sheep in the usual manner (12). The sheep were fed a ration consisting of 500 gm. of English hay, 150 gm. of gluten feed, 200 gm. of finely ground vegetable-ivory meal, and 10 gm. of salt with water *ad libitum*. Rations for the entire test were weighed out at the beginning and samples sent to the laboratory and immediately analyzed. The results are given in Table IV.

TABLE IV.—*Percentage composition of feedstuffs used in Experiment I*

MOISTURE

Constituent.	Hay.	Gluten feed.	Vegetable-ivory meal.
Moisture	11. 95	10. 07	12. 64
Dry matter	88. 05	89. 93	87. 36
Total	100. 00	100. 00	100. 00

DRY MATTER

Ash	5. 81	1. 11	1. 37
Protein	9. 34	26. 96	6. 02
Fat	2. 88	3. 94	. 67
Fiber	31. 70	8. 70	7. 02
Nitrogen-free extract	50. 78	59. 29	84. 90
Total	100. 00	100. 00	100. 00

The experiment lasted 14 days, 7 of which were preliminary; and during that time no disturbances in digestion were observed. The sheep ate the vegetable-ivory mixture readily.

One-tenth of the daily manure excreted by each sheep was carefully dried and preserved. Later these portions were composited and analyzed, the results being given in Tables V and VI.

TABLE V.—*Quantities of manure and urine excreted and water consumed daily by sheep fed vegetable-ivory meal, gluten feed, and hay*

SHEEP 5

Date.	Manure.			Urine.	
	Total weight.	Weight of the one-tenth preserved.	Air-dry weight.	Weight.[a]	Nitrogen in urine.
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Per cent.*
Nov. 16	711	71. 1	29. 25	2, 151	0. 48
Nov. 17	626	62. 6	28. 20	975	. 83
Nov. 18	684	68. 4	28. 63	1, 397	. 58
Nov. 19	476	47. 6	21. 20	2, 201	. 64
Nov. 20	476	47. 6	20. 45	1, 135	. 68
Nov. 21	536	53. 6	23. 37	1, 459	. 57
Nov. 22	615	61. 5	25. 37	914	. 80
Average	589	58. 9	25. 21	1, 461	. 65

SHEEP 6

Nov. 16	535	53. 5	25. 21	621	1. 73
Nov. 17	527	52. 7	25. 45	665	1. 34
Nov. 18	495	49. 5	23. 21	681	1. 25
Nov. 19	483	48. 3	23. 39	547	1. 42
Nov. 20	545	54. 5	25. 89	643	1. 40
Nov. 21	407	40. 7	19. 93	543	1. 08
Nov. 22	512	51. 2	26. 28	647	1. 31
Average	507	50. 7	24. 19	621	1. 36

[a] The quantity of urine in each case was increased by 100 c. c. of carbolic disinfectant and wash water used at the barn.

TABLE VI.—*Percentage composition of feces of sheep fed vegetable-ivory meal, gluten feed, and hay*

MOISTURE

Constituent.	Sheep 5.	Sheep 6.
Moisture	5. 70	5. 50
Dry matter	94. 30	94. 50
Total	100. 00	100. 00

DRY MATTER

Ash	9. 16	9. 80
Protein	15. 60	14. 70
Fat	3. 96	3. 44
Fiber	25. 96	25. 34
Nitrogen-free extract	45. 32	46. 72
Total	100. 00	100. 00

The sheep were weighed on the first two and the last two days of the digestion period and the average taken to determine gain or loss in body weight (Table VII).

TABLE VII.—*Gain or loss in weight (pounds) by sheep fed vegetable-ivory meal, gluten feed, and hay*

Sheep No.	Weight at beginning.	Weight at end.	Gain.	Loss.
5	139. 25	137. 25	.....	2. 00
6	160. 13	163. 83	3. 70	.....

As a supplementary check on the metabolism of the sheep, the urine was collected, weighed, and sampled daily, and the nitrogen determined. A study of Table VIII shows that sheep 5 excreted more nitrogen than was supplied in its food. This sheep lost in weight. Sheep 6, however, gained in body weight, and it will be noted that less nitrogen was given off than was consumed.

TABLE VIII.—*Nitrogen balance of sheep fed vegetable-ivory meal, gluten feed, and hay*

[Estimated in grams of protein.]

Sheep No.	Consumed.	Excreted.	Gain.	Loss.
5	647. 92	659. 07	.....	11. 15
6	647. 92	606. 69	41. 23	.....

By applying the analyses in Table IV to the total rations fed, the total amounts of dry matter and food constituents are obtained. From these the amounts of the several constituents of the manure (calculated by the use of Table VI) are subtracted. The remainder is the quantity of hay, gluten, and vegetable-ivory meal digested. By subtracting from this the amount of hay and gluten digested [1] the amount and percentage of the vegetable ivory digested is obtained (Table IX).

[1] Obtained by applying the digestion coefficients of hay and gluten alone to the quantity fed.

TABLE IX.—*Daily consumption and excretion (in grams) and the digestion coefficients of sheep fed vegetable-ivory meal, gluten feed, and hay*

SHEEP 5

Item.	Dry matter.	Protein.	Fat.	Fiber.	Ash.	Nitrogen-free extract.
550 gm. of English hay	484. 28	45. 67	11. 04	153. 52	28. 14	245. 91
150 gm. of gluten feed	134. 90	36. 37	5. 32	11. 74	1. 50	79. 97
200 gm. of vegetable ivory	174. 72	10. 52	1. 21	12. 27	2. 39	148. 33
Amount consumed	793. 90	92. 56	17. 57	177. 53	32. 03	474. 21
Minus 252.10 gm. of manure	237. 73	37. 09	9. 41	61. 71	21. 78	107. 74
Hay, gluten, and vegetable ivory digested	556. 17	55. 47	8. 16	115. 82	10. 25	366. 47
Minus hay and gluten digested	408. 66	55. 79	9. 16	109. 07	9. 19	228. 12
Vegetable ivory digested	147. 51	.....	.....	6. 75	1. 06	138. 35
Percentage digested	84. 43	.....	.....	55. 01	44. 35	93. 27

SHEEP 6

Amount consumed (as per sheep 5)	793. 90	92. 56	17. 57	177. 53	32. 03	474. 21
Minus 241.94 gm. of manure	228. 63	33. 61	7. 86	57. 93	22. 41	106. 82
Hay, gluten, and vegetable ivory digested	565. 27	58. 95	9. 71	119. 60	9. 62	267. 39
Minus hay and gluten digested	408. 66	55. 79	9. 16	109. 07	9. 19	228. 12
Vegetable ivory digested	156. 61	3. 16	. 55	10. 53	. 43	139. 27
Percentage digested	89. 63	30. 04	45. 45	85. 82	17. 99	93. 89
Average percentage for both sheep	87. 03	[a] 30. 04	[a] 45. 45	70. 42	31. 17	93. 58
Percentage digestibility of English hay and gluten as previously determined [b]	66	68	56	66	31	70

[a] One sheep only.

[b] Obtained from previous digestion experiments similar to the one under discussion, in which a part of the same lot of hay and gluten feed was used.

Table IX shows that the two digestion trials for nitrogen-free extract agree very closely. It is to be noted further that this extract matter constituted about 85 per cent of the total dry matter of the vegetable-ivory meal and that it had a digestibility of 94 per cent. In the case of the fat and ash the results are uncertain, but this is not surprising because so very little of these two ingredients is present. The digestibility of the fiber is not very satisfactory, and the same may be said of the protein. The percentages of these two ingredients, however, in the vegetable-ivory meal are relatively small.

EXPERIMENT II.—In another similar experiment conducted with three sheep and a different sample of vegetable-ivory meal the following digestion coefficients were obtained. With them are compared the results of Experiment I as well as the average coefficients for corn meal (Table X).

TABLE X.—*Comparison of the digestion coefficients obtained in Experiments I and II*

Experiment No.	Feed.	Number of sheep.	Dry matter.	Protein.	Fat.	Fiber.	Nitrogen-free extract.
I	Vegetable ivory	2	87	30	[a] 45	70	94
II	do	3	81	[b] 41	56	73	89
Average			84	36	51	72	92
Corn meal (13, p. 295)			88	67	90	.....	92

[a] One sheep only. [b] Different sheep showed variable results.

Of these figures the first and last two columns demand the most attention. Corn meal contains nearly as much nitrogen-free extract as the vegetable ivory, and it would appear that the percentage digestibility of this ingredient in each feed is approximately the same.

Applying the average coefficients to the composition of the dry matter of the vegetable-ivory meal and the average coefficients for corn meal to the dry matter contained in the latter [1] and multiplying by 2,000, one obtains the following amounts of digestible matter in 1 ton of each of the two feeds (Table XI).

TABLE XI.—*Digestible nutrients (in pounds) in vegetable-ivory meal and corn meal per ton*

Feed.	Protein.	Fat.	Fiber.	Nitrogen-free extract.	Total.
Vegetable ivory	42.34	6.83	101.08	1,582.20	1,732.45
Corn meal	147.52	78.84	.....	1,486.40	1,712.76

On the basis of total digestible organic matter the results indicate that the vegetable-ivory meal is equal in feeding value to corn meal. Kellner (10) and Armsby and Fries (3, 4, 5, 6) have shown, however, that it is not possible to estimate with accuracy, by means of digestion experiments, the relative value of different feedstuffs. In view of the excess of fiber in the vegetable-ivory meal over that of the corn meal (7 per cent in ivory meal *v.* 2 per cent in corn meal), of the tough horny nature of the ivory nut, of the uncertainty of the nutritive value of the mannan as compared with starch, and of the unknown influence of the two feedstuffs

[1] The average composition of corn meal on a dry-matter basis in Lindsey's compilations (12) is protein 11.01 per cent, fat 4.38 per cent, fiber 2.25 per cent, and nitrogen-free extract 80.79 per cent.

on metabolism, one is justified in assuming that the vegetable-ivory meal can not have as high a nutritive effect as has the corn meal.

EXPERIMENT III.—As another means of determining how completely vegetable-ivory meal was digested, Experiment III was undertaken, feeding the same amounts of the several feeds as in Experiment I. The basal ration consisted of hay and gluten feed, and the ration proper of the same feeds in like quantities, plus 200 gm. of vegetable-ivory meal. Each ration was fed for 14 consecutive days, the feces being collected for the last 7 days in each period, and aliquots preserved. In this experiment the hay, gluten feed, and vegetable-ivory meal ration preceded the basal ration of hay and gluten feed. The feces were tested for total sugar after acid hydrolysis, to note whether the percentage of sugar was higher in the ivory-meal period than in the period without the meal. It is understood that little or no sugar should appear as such in normal feces, and the relatively large amounts which are reported below are accounted for as a result of the hydrolysis of pentosans and other hemicelluloses, largely from the hay. It was necessary to hydrolyze with strong acid and boiling in order to include completely the sugar of the vegetable ivory, if any, which might have passed through the animal unchanged.

On a dry-matter basis it was found that the average carbohydrate content, estimated as dextrose, for the feces of the hay, gluten, and ivory-meal period was 25.46 per cent and that for the hay and gluten period was 24.68 per cent. In other words, the total amount of carbohydrates, so called, found in the feces when vegetable ivory had been included in the ration was only 0.78 per cent more than was found when it had not been included. This is relatively such a small amount that it seems safe to conclude that very little, if any, of the carbohydrate of the vegetable ivory escaped undigested. The mannan therefore appears to have been quite thoroughly hydrolyzed and assimilated by the sheep.

FEEDING EXPERIMENTS

EXPERIMENT I.—During March, April, and May, 1914, an experiment to compare the relative feeding value of vegetable-ivory meal and corn meal was carried out and may be described as follows:

Three pairs of cows were fed for periods of five weeks each, exclusive of preliminary periods of 10 days, on basal rations consisting daily for each cow of substantially 2.5 pounds of wheat bran, 2.5 pounds of cottonseed meal, and what hay the animals would eat clean (about 20 pounds). Either 3 pounds of vegetable-ivory meal or 3 pounds of corn meal were fed in addition. The experiment was conducted on the reversal plan—that is, one cow of each pair was fed the basal ration plus the vegetable ivory for five weeks, while the other received corn meal; then the ration was reversed for five weeks (Table XII).

TABLE XII.—*Average daily ration (in pounds) consumed per cow in Feeding Experiment I*

Character of ration.	Hay.	Bran.	Cottonseed meal.	Corn meal.	Vegetable-ivory meal.
Corn meal	20. 58	2. 36	2. 28	3. 36	.....
Vegetable-ivory meal	20. 46	2. 36	2. 28	1	3

Daily samples of the grain and ivory meal were taken and preserved in glass-stoppered bottles. These were brought to the laboratory for analysis at the end of each half of the trial. The hay was sampled three times during each half and determinations of moisture made and aliquots preserved for analysis.

Milk samples were taken for five consecutive days in the first, third, and fifth weeks of each half of the test and analyzed for fat and total solids.

The cows were weighed on two consecutive days at the beginning and end of each half of the experiment.

The cows averaged 0.12 of a pound more hay daily while on the corn-meal ration. The 1 pound of corn meal fed during the vegetable-ivory period applied only to two of the cows for periods of 35 days each.

From the analyses of the materials fed, their digestibility coefficients, and the amounts daily consumed, the quantity of digestible organic nutrients received daily per cow was estimated, the results being given in Table XIII.

TABLE XIII.—*Quantity of digestible organic nutrients in the average daily ration of cows in Feeding Experiment I*

Character of ration.	Protein.	Fat.	Fiber.	Nitrogen-free extract.	Total.	Nutritive ratio.
Corn meal	2. 03	0. 53	4. 07	8. 86	15. 47	1 : 6. 9
Vegetable-ivory meal	1. 88	. 43	4. 29	9. 17	15. 77	1 : 7. 6

It will be noticed that the total digestible carbohydrates were slightly greater for the vegetable-ivory ration than for the corn-meal ration. On the other hand, protein and fat show a favorable balance for the corn-meal ration.

At the completion of the experiment a distinct gain in herd weight was noticed when the corn-meal ration was fed over that of the vegetable-ivory ration (Table XIV).

TABLE XIV.—*Gain or loss (in pounds) in herd weight in Feeding Experiment I*

Character of ration.	Gain.	Loss.	Average per cow.	
			Gain.	Loss.
Corn meal	94	.....	15. 6	.....
Vegetable-ivory meal	6	.....	1. 0	.....

Table XV records the total yield of milk and milk ingredients per cow for each ration, as well as the total yield of the herd.

TABLE XV.—*Total yield of milk and milk ingredients from different rations in Feeding Experiment I*

Name of cow.	Time.	Milk.	Solids.		Fat.		Butter.[a]
	Weeks.	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*	*Pounds.*
CORN-MEAL RATION							
Samantha II..	5	1,184.6	12.57	148.9	4.03	47.7	54.9
Fancy III....	5	1,131.8	12.90	146.0	4.33	49.0	57.2
Betty.....	5	761.6	13.76	104.8	4.77	36.3	42.3
Betty II.....	5	933.4	13.76	128.8	4.75	44.3	51.7
Amy.....	4	673.8	13.45	90.6	4.68	31.5	36.7
Amy II.....	4	558.3	14.75	82.3	5.45	30.4	35.5
Total...	28	5,243.5	[b] 13.37	701.0	[c] 4.56	239.2	278.3
VEGETABLE-IVORY-MEAL RATION							
Samantha II..	5	1,200.6	12.70	652.5	4.13	49.6	57.9
Fancy III....	5	1,001.6	13.01	130.3	4.53	45.4	53.0
Betty.....	5	805.0	13.80	111.1	4.93	39.7	46.3
Betty II.....	5	897.6	13.61	122.2	4.49	40.3	47.0
Amy.....	4	620.7	13.26	82.3	4.74	29.4	34.8
Amy II.....	4	547.2	15.15	82.9	5.79	31.7	37.0
Total...	28	5,072.7	[b] 13.43	681.3	[c] 4.65	236.1	276.2

[a] Butter equals fat plus one-sixth.

[b] Averages obtained by dividing the total weight of solids by the total weight of milk.

[c] Averages obtained by dividing the total weight of fat by the total weight of milk.

One hundred and seventy pounds more milk were produced by the corn-meal ration than by the vegetable-ivory-meal ration. This excess is not pronounced; and while it is possible that the difference may be within the limit of experimental error when taken together with the fact that the corn-meal ration increased the live weight of the cows, it indicates at least that the corn meal was somewhat superior to the vegetable-ivory meal as a source of nutrition.

TABLE XVI.—*Average percentage composition of milk of the herd in Experiment I on each ration*

Character of ration.	Total solids.	Fat.	Solids not fat.
Corn meal.....	13.37	4.56	8.81
Vegetable-ivory meal.....	13.43	4.65	8.74

The very concisely stated data of Table XVI of this experiment indicate that vegetable-ivory meal possesses a distinct feeding value and that, while somewhat inferior to corn meal, the difference is not marked.

As greater difficulty was met with in hydrolizing the carbohydrate of the vegetable ivory than the carbohydrate of other feeding materials, it

would seem reasonable to suppose that the same relation would hold true in the digestive processes of animals. This being the case, more of the total energy of the material would be used up in digestion and assimilation, which otherwise might be used for milk production.

EXPERIMENT II.—A short experiment with three cows, supplementary to Experiment I, was carried out during January and February of 1915. A basal ration somewhat below what the cows needed for maintenance and milk was fed for two weeks. Then the cows were given 3 pounds of vegetable-ivory meal in addition for two weeks. During the fifth and sixth weeks the cows were again given only the basal ration. The object was to see whether the animals would show any increase in weight or milk production in response to the addition of the ivory meal.

TABLE XVII.—*Average daily ration (in pounds) consumed per cow in Feeding Experiment II*

Character of ration.	Hay.	Wheat bran.	Cottonseed meal.	Hominy.	Vegetable-ivory meal.
Basal	18. 67	2. 34	2	1	.....
Vegetable-ivory meal	18. 67	2. 34	2	1	3

The quantity and quality of the milk was determined for the second week of each section of the experiment. Samples were taken in the usual way and the animals were weighed on two consecutive days at the beginning and end of each second week.

Little can be said about body weight, as the periods were of too short duration.

TABLE XVIII.—*Yield of milk and milk ingredients from different rations in Feeding Experiment II*

BASAL RATION, JANUARY 20–26

Name of cow.	Milk.	Fat.		Solids.	
	Pounds.	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*
Amy	196. 5	5. 50	10. 81	13. 77	27. 06
Betty III	137. 6	4. 70	6. 47	13. 23	18. 20
Red III	121. 9	5. 38	6. 56	13. 86	16. 90
Total	456. 0	[a] 5. 22	23. 84	[a] 13. 63	62. 16

VEGETABLE-IVORY-MEAL RATION, FEBRUARY 3–9

Amy	199. 2	4. 90	9. 76	13. 14	26. 17
Betty III	158. 0	4. 58	7. 24	13. 25	20. 94
Red III	125. 1	5. 28	6. 61	13. 71	17. 15
Total	482. 3	[a] 4. 90	23. 61	[a] 13. 30	64. 26

BASAL RATION, FEBRUARY 21–27

Amy	190. 3	4. 80	9. 13	13. 12	24. 97
Betty III	146. 4	4. 60	6. 73	13. 31	19. 49
Red III	125. 4	5. 38	6. 75	13. 93	17. 47
Total	462. 1	[a] 4. 89	22. 61	[a] 13. 21	61. 93

[a] Average obtained by dividing the total number of pounds of fat or solids by the total number of pounds of milk.

Though of short duration, the experiment shows the favorable effects of the addition of 3 pounds per cow daily of the ivory meal to the basal ration. This addition increased the milk flow 5.7 per cent, and its removal caused a decrease of 4.2 per cent.

Another experiment in which a basal ration with and without vegetable-ivory meal was fed three cows was carried on for a period of 81 days. The addition of the meal was followed by an increase in milk yield and its removal resulted in a milk shrinkage. This trial, together with the one just described, shows that the ivory meal possesses a distinct nutritive value.

EXPERIMENT III.—In Experiment I a definite quantity of vegetable-ivory meal was compared with an equal quantity of corn meal. In order to demonstrate more fully the effect of the vegetable ivory, a herd of six cows was put on a basal ration of hay, bran, cottonseed meal, and hominy meal for four weeks, exclusive of a preliminary period of 10 days, during which time three received in addition a quantity of the ivory meal. After this period, which will be known as the first half of the experiment, conditions were reversed, and during the four weeks of the second half the first three cows went without the vegetable-ivory meal while the others received it.

Each cow was weighed before watering and feeding on two consecutive days at the beginning and end of each half of the trial. Samples of hay were taken at the beginning, middle, and end of each half, while the grains were sampled daily. The milk of each cow was sampled in the usual manner on the first, third, and fourth week of each half. The results are given in Tables XIX and XX.

TABLE XIX.—*Average daily ration (in pounds) consumed per cow in Feeding Experiment III*

Character of ration.	Hay.	Wheat bran.	Cottonseed meal.	Hominy.	Vegetable-ivory meal.
Basal plus vegetable-ivory meal...	18. 32	2. 30	2. 22	1. 57	2. 79
Basal minus vegetable-ivory meal.	18. 31	2. 31	2. 23	1. 57	.....

TABLE XX.—*Quantity of digestible organic nutrients in the average daily ration of Feeding Experiment III*

Character of ration.	Protein.	Fat.	Fiber.	Nitrogen-free extract.	Total.	Nutritive ratio.
Basal plus vegetable-ivory meal.....	2. 50	0. 61	3. 04	10. 37	16. 52	1:5. 90
Basal minus vegetable-ivory meal.....	2. 11	. 60	2. 92	8. 36	13. 99	1:5. 97

In order to avoid excessive feeding, a basal ration was fed which was rather below what each animal needed for maintenance and normal milk production. This was calculated on the basis of the writers' knowledge of the individual animal and with the aid of Haecker's standards (8). The addition of the vegetable-ivory meal to this basal ration should therefore prove its distinctive feeding value.

In Table XXI will be found the total yield of milk, fat, and solids produced by each ration.

TABLE XXI.—*Total yield of milk and milk ingredients in Feeding Experiment III*

BASAL RATION PLUS VEGETABLE-IVORY MEAL

Name of cow.	Milk.	Solids.		Fat.		Butter.[a]
	Pounds.	*Per cent.*	*Pounds.*	*Per cent.*	*Pounds.*	*Pounds.*
Fancy III	1,057.2	13.00	137.43	4.67	49.37	57.6
Betty III	599.0	13.55	81.16	4.72	28.27	33.0
Ida II	608.4	14.38	87.49	5.33	32.43	37.8
Betty	676.0	12.96	87.61	4.39	29.68	34.6
Red III	312.5	15.12	47.25	5.29	16.53	18.3
Amy	705.9	13.27	93.67	4.78	33.74	39.4
Total	3,959.0	[b] 13.50	534.61	[b] 4.79	190.02	220.7

BASAL RATION MINUS VEGETABLE-IVORY MEAL

Fancy III	970.1	12.52	113.56	4.26	41.33	48.2
Betty III	477.1	12.95	61.78	4.49	21.42	25.0
Ida II	531.7	12.95	68.86	5.16	27.44	32.0
Betty	706.7	13.16	93.00	4.62	32.65	38.1
Red III	433.2	14.38	62.29	5.25	22.74	26.5
Amy	707.8	13.14	93.00	4.84	34.26	40.0
Total	3,826.6	[a] 12.87	492.49	[a] 4.70	179.84	209.8

[a] Butter equals fat plus one-sixth.

[b] Averages obtained by dividing the total weight of fat or solids by the total weight of milk.

It will be noticed here that the ivory-meal ration produced 132.4 pounds more milk than the other ration, an increase of 3.46 per cent. Inasmuch as the total feed consumed was identical in each ration with the exception of 470 pounds of the vegetable-ivory meal, one may conclude in the case of this particular experiment that the 132.4 pounds of milk were produced by the 470 pounds of ivory meal, or that it required 3.56 pounds to produce 1 pound of milk.

If rather less of the basal ration had been fed and more of the vegetable-ivory meal, it is probable that the effect of the latter would have been more pronounced.

EXPERIMENT IV.—Another feeding experiment comparing vegetable-ivory meal and corn meal was carried out during January, February, and March, 1916, with eight cows. In this case, as in Experiment I,

the reversal method was employed, each period continuing five weeks, in addition to the preliminary period. Hay, bran, and cottonseed meal composed the basal ration, to which were added like amounts of dry matter in the form of corn meal or ivory meal (Tables XXII and XXIII). Only a summary is here presented.

All the customary precautions were taken to make the experiment as accurate and representative as possible. The milking was done at the same time each morning and evening, and the animals were weighed at regular intervals. All feed and milk samples were taken in the usual manner.

TABLE XXII.—*Average daily ration (in pounds) consumed per cow in Feeding Experiment IV*

Character of ration.	Hay.	Bran.	Cottonseed meal.	Corn meal.	Vegetable-ivory meal.
Vegetable-ivory meal	18. 5	2. 38	2. 19	.....	3. 75
Corn meal	18. 5	2. 38	2. 19	4. 01	.....

TABLE XXIII.—*Quantity of digestible organic nutrients in the average daily ration in Feeding Experiment IV*

Character of ration.	Protein.	Fat.	Fiber.	Nitrogen-free extract.	Total.	Nutritive ratio.
Vegetable-ivory meal	1. 88	0. 44	3. 58	9. 06	14. 96	1:7. 24
Corn meal	2. 07	. 55	3. 38	9. 01	15. 01	1:6. 57

The calculations indicate that the herd consumed substantially like amounts of digestible nutrients in each of the two rations. One would expect a like effect on body weight and milk production. As in Experiment III, care was taken to feed less digestible nutrients than was required for maintenance and milk yield according to the Haecker standard, in order to secure the maximum effect of each ration. The results indicate that this object was in a measure at least achieved. The herds uffered a loss of weight on each ration, the loss being the greater on the one containing vegetable-ivory meal, 95 pounds, as against 38 pounds for the corn-meal ration.

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TABLE XXIV.—*Total yield of milk and milk ingredients in Feeding Experiment IV*

VEGETABLE-IVORY-MEAL RATION

Name of cow.	Total milk.	Solids.		Fat.	
		Average percentage.	Pounds.	Average percentage.	Pounds.
	Pounds.				
Amy	852. 1	13. 60	115. 89	5. 14	43. 80
Betty III	798. 2	13. 30	106. 16	4. 76	37. 99
Cecile II	658. 2	14. 76	97. 15	5. 58	36. 73
White	676. 0	13. 54	91. 53	5. 19	35. 08
Betty II	775. 8	13. 75	106. 67	4. 94	38. 32
Red III	576. 1	13. 69	78. 87	5. 33	30. 71
Red IV	723. 5	13. 29	96. 15	4. 60	33. 28
Samantha II	1, 343. 4	12. 64	169. 81	4. 46	59. 92
Total	6, 403. 3	[a] 13. 47	862. 23	[a] 4. 93	315. 83

CORN-MEAL RATION

Amy	1, 001. 0	13. 23	132. 43	4. 93	49. 25
Betty III	851. 0	12. 83	109. 18	4 43	37. 70
Cecile II	744. 4	14. 28	106. 30	5. 22	38. 86
White	704. 8	14. 10	99. 38	5. 09	35. 87
Betty II	840. 6	13. 83	116. 25	4. 94	41. 53
Red III	599. 5	13. 88	83. 21	5. 39	32. 31
Red IV	736. 0	14. 29	105. 17	5. 20	38. 27
Samantha II	1, 454. 0	12. 65	183. 93	4. 39	63. 83
Total	6, 931. 3	[a] 13. 50	935. 85	[a] 4. 87	337. 72

[a] Averages obtained by dividing the total weight of fat or solids by the total weight of milk.

Table XXIV shows that the corn-meal ration produced an increase of 528 pounds of milk, or approximately 8 per cent over that produced by the ivory-meal ration. The total solids were also increased 73.62 pounds and the milk fat 21.89 pounds. The cows in this experiment were in an earlier stage of lactation than those used in the previous trials, and the results are to be regarded as the most satisfactory. It is evident that while the vegetable-ivory meal possesses a distinct feeding value, a given amount has not the feeding equivalent of the same amount of corn meal. The methods of experimentation with milch cows are not sufficiently sharp to enable one to draw accurate deductions as to the exact relative feeding effect of the two materials.

CONCLUSIONS

(1) Analyses show vegetable ivory to be carbohydrate in nature, containing about 5 per cent of protein and 75 per cent of nitrogen-free extract. Fat and mineral matter are negligible, while crude fiber averages 7 per cent.

(2) Ninety-two and one-half per cent of the nitrogen-free extract is mannan, a polymer of mannose sugar.

(3) Pentosans are present to the extent of 2.5 per cent.

(4) Lignin, galactan, starch, and dextran are not found in vegetable ivory.

(5) A nonnitrogenous "alcoholic precipitate" amounting to about 2.5 per cent is present which is not pentose in nature. It differs from fruit "pectin" in that it does not form mucic acid and does not reduce copper.

(6) By the use of Fehling's solution about 0.5 per cent of water-soluble reducing material and 2 per cent of so-called total sugars are shown to be present after inversion with hydrochloric acid in the cold.

(7) The mannan in vegetable ivory is not entirely hydrolyzed without at least 4½ hours' boiling in an acid solution. The characteristic "acid" color of the solution bleaches out at the completion of hydrolysis.

(8) With continued acid boiling the use of Fehling's solution gives results which, when estimated as dextrose, agree closely with the percentage of nitrogen-free extract minus the percentage "pectin" present. Otherwise stated, practically the entire nitrogen-free extract is accounted for in the form of a hexose sugar or its condensation product, except a small percentage of pentoses and pectin.

(9) The energy equivalent of the material ranks well with other carbohydrate foods, and it possesses a fuel value equal to one-half that of soft coal.

(10) Sheep ate vegetable-ivory meal readily when it was mixed with other grains and digested it very thoroughly. Eighty-four per cent of the dry matter and ninety-two per cent of the nitrogen-free extract were digested.

(11) All the carbohydrates appeared to have been hydrolyzed and absorbed in the digestive tract.

(12) Cows ate the material when mixed with other feed, without evidence of digestive disturbances. They refused to eat it if fed by itself.

(13) When fed as an addition to a basal ration, the increase in milk was sufficient to indicate its positive value as a productive feed.

(14) Though the methods of feeding necessarily followed were not such that exact relative values could be shown, it seems certain that vegetable-ivory meal does not fully equal corn meal for milk production.

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ROSY APPLE APHIS

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INTRODUCTION

The rosy apple aphis is undoubtedly the most injurious leaf-feeding apple aphis. Its attacks not only injure the foliage and deform the growing apple trees (*Malus sylvestris*), but when abundant or unchecked it deforms the fruit, causing the production of "aphis apples," which are unfit for sale. The experiments on which the present paper is based were conducted during the seasons of 1914 and 1915 and the manuscript prepared for publication during the winter of 1915–16. Besides the work recorded in the present paper a study of the embryology was undertaken. This work still remains to be completed, the present paper recording the life history only after the hatching of the egg.[1]

NOMENCLATURE OF ROSY APPLE APHIS

The proper scientific name for the rosy apple aphis has for some years been in doubt. Pergande, as shown by his manuscript notes, always considered it to be *Aphis malifoliae* Fitch. Other American writers usually adopted the view that this name became a synonym of *A. sorbi* Kalt. In studying European specimens and the literature carefully the writers have come to the conclusion that *A. malifoliae* is the only name to apply to the species. Their reasons for this view are pointed out under the different names following.

Aphis malifoliae Fitch, 1854.—Fitch (4, p. 760–761; Repr. p. 56–57)[2] separated our rosy aphis from his *mali* Fab. in connection with his

[1] During the course of the study the writers were assisted by Miss Dorothy Walton and by Mr. James Luckett. Mr. Luckett handled a large number of the experiments during the summer of 1915.

[2] Reference is made by number to "Literature cited," p. 342-343.

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discussion of that species. No complete description was given but enough was recorded to leave no doubt that he had our well-known rosy aphis. The fact that he referred to the winged form as almost entirely black is given by Gillette as sufficient evidence for rejecting the name as not applicable to the insect herein considered. It must be remembered, however, that the insects to which he referred were fall migrants (taken on October 4). These fall migrants are usually much darker than the spring migrants and the writers have reared many at Vienna, Va., which were a uniform jet-black. There seems very good reason, then, for accepting Fitch's name as referring to the species, and since *A. sorbi* and *A. pyri* prove to be distinct, *A. malifoliae* Fitch is the name that must stand for the species.

Aphis pyri Boyer de Fonscolombe, 1841.—This name (1) is the earliest one that has been applied to our rosy aphis. Gillette and Taylor (7, p. 31–32) referred the species to it when they found themselves unable to accept *A. sorbi* Kalt. The original description, however, will not fit our insect, and, although later descriptions given under this name might do so, it will for this reason be impossible to use the name for our common rosy aphis. It may be that Gillette and Taylor based their identification upon the description referred to Boyer's species by Koch (3).

In redescribing what he thought to be the *A. crataegii* of Kaltenbach (2) as well as the *A. pyri* of Boyer, Koch based his descriptions entirely upon apple forms. In this he was describing the forms doubtfully referred to *A. crataegii* by Kaltenbach, but seemingly not the true *A. crataegii* of that author. The description given agrees very closely with our apple insect. It would seem, therefore, that the descriptions of *A. crataegii* Kalt. and *A. pyri* Boyer refer to another insect, but the *A. pyri* Boyer of Koch (3, p. 108–110, fig. 145, 146) is the *A. malifoliae* of Fitch. This insect, however, must be distinguished from the *A. pyri* of Koch (3, p. 60), which is quite a distinct species and has been renamed *A. kochii* by Schouteden.

Aphis crataegii Kaltenbach, 1843.—Kaltenbach (2, p. 66–67) described a species under this name from the white thorn. The description as given does not agree with specimens of the insects under consideration. It seems evident, then, that this name can not be applied to the rosy aphis. In his description, however, Kaltenbach refers to specimens taken on apple which he believed might be the same as those on thorn. It seems to the writers that these forms are the same as ours upon apple and that Kaltenbach was in error in considering them to be the same species as his specimens on thorn. This is indicated by his comparison between the two.

Aphis sorbi Kaltenbach, 1843.—This species (Pl. 20, A) was described (2, p. 70–71) from specimens on Sorbus. This is the name now most uniformly applied to the rosy apple aphis in this country. The first

application of the name here appears to have been made by Sanderson (5, p. 189–191), who went rather fully into the history of the species.

In some characters our rosy apple aphis does not fit the description given by Kaltenbach, and these characters cause the writers to believe that they are dealing with another insect. This belief is strengthened after examination of the European insects. Collections of *A. sorbi* from Sorbus, taken by Mr. J. F. Strauss in Germany, being from the same region and the same host as the original specimens, can with some certainty be considered typical. Moreover, they fit very closely the original description of Kaltenbach.

Although these specimens are in a general way very close indeed to the rosy apple aphis, a careful comparison shows that they represent a distinct species (Pl. 22, C). In the wingless form the cornicles are considerably longer than are those of the rosy apple aphis, and the lateral tubercles are more prominent. The antennæ, too, show a considerable difference, the length of IV, as compared with V, being much less in *A. sorbi* than in the rosy aphis. These characters are well illustrated in Table I.

TABLE I.—*Relative proportions of antennæ and cornicles of wingless forms of Aphis sorbi and A. malifoliae*

Aphis sorbi.					*Aphis malifoliae.*				
Segment III.	Segment IV.	Segment V.	Segment VI.	Cornicle.	Segment III.	Segment IV.	Segment V.	Segment VI.	Cornicle.
22	15	14	8 –24	24	28	20	14	6. 5–27	20
24	17	16	6. 5–22	25	28	19. 5	14	6. 5–28	19
26	17	14	6. 5–25	23	25	21	14	6. 5–27	20
23	16	15	7 –23	22	30	21	15	6. 5–32	20

The winged forms of the two species, while very much alike in general appearance and color characters, can be separated quite easily by measurements of the antennal segments. The specimens of *A. sorbi* show the base of Segment VI considerably longer and the unguis considerably shorter than the same portions of Segment VI of the rosy aphis. The large number of sensoria on the antennæ of the two species cause them to resemble each other very closely.

Measurements of the antennæ of six specimens chosen at random from the two species are given in Table II, together with the number of sensoria on the different segments.

A glance at these data will show a fairly constant difference between the spring migrants of these two forms, and this structural difference is borne out by the writers' experiments. They have been unable to rear the rosy aphis on the host plant of the European *A. sorbi*. The European form they have been unable to test on apples on account of the lack of live material.

TABLE II.—*Relative proportions of antennæ and number of sensoria of winged forms of Aphis sorbi and A. malifoliae*

Aphis sorbi.								*Aphis malifoliae.*							
Segment III.		Segment IV.		Segment V.		Segment VI.		Segment III.		Segment IV.		Segment V.		Segment VI.	
Length.	Sensoria.	Length.	Sensoria.	Length.	Sensoria.	Base.	Unguis.	Length.	Sensoria.	Length.	Sensoria.	Length.	Sensoria.	Base.	Unguis.
34	61	23	23	19	15	10	28	36	60	23	29	15	7	6	30
34	60	24	25	20	10	10	27	38	53	24	27	16	6	6	32
34	53	23	24	20	13	10	29	37	55	24	27	17	10	7	35
34	67	24	24	21	11	9	27	37	63	21	22	15	7	6	35
35	57	22	24	18	9	9	26	36	53	24	27	17	5	7	35
35	64	24	24	20	11	10	27	35	54	22	23	14	4	6	31

Aphis kochii Schouteden, 1903 (Pl. 20, B).—This name was given by Schouteden (6, p. 185) to the species described as *A. pyri* by Koch, since Boyer's species already was called by that name. It was found by Koch curling the leaves of *Pyrus pyraster*. The description given by Koch does not agree with our apple insect, but it does agree with another species occurring on apple in Germany, of which the writers have specimens. Two species were collected from the apple in Germany at the same time, one which seems undoubtedly to be *A. malifoliae* and another which is very similar to it but having short cornicles.

In describing his *A. pyri* Koch says (3, p. 60): "Honigrohrchen sehr kurz, etwas walzenförmig." His figures also show short cornicles which are very unlike those of the rosy aphis, but very much like those of the other species. The writers believe, therefore, that *A. kochii* is quite a distinct species from *A. malifoliae*.[1]

Myzus plantaginis Passerini? (Pl. 24, *A*).—A species of Myzus occurring commonly on the broad-leaved plantain in this country must be distinguished from the rosy apple aphis occurring on plants of the same genus. This is a very simple process where winged forms of the species are present. These have the wing veins bordered with dusky, giving the venation a much heavier appearance than it has in the rosy aphis. The third segment, moreover, of the antennæ has one simple row of sensoria, whereas the same segment of the rosy aphis is crowded with sensoria. When, however, only wingless forms are present, the two species look remarkably alike and there would seem to be almost as much reason for calling the one a species of Myzus as the other. The measurements, too, are very similar, but Segment V of *M. plantaginis* nearly always averages a little longer than Segment IV, whereas in the

[1] Since the account just given was written, Theobald (10, p. 202–210) places *A. malifoliae* Fitch, 1856, as a synonym of *A. kochii* Schouteden, 1903. As shown herein, the two are distinct, but *A. pyri* Boyer of Koch is *A. malifoliae* Fitch.

rosy aphis the reverse is true, Segment IV being usually the longer. Segment III of *M. plantaginis* is also relatively shorter than is the same segment in the rosy apple aphis.

The synonymy of the rosy apple aphis will thus stand as follows:

Aphis malifoliae Fitch

Aphis pyri Boyer of Koch (but not *A. pyri* Boyer nor *A. pyri* Koch).

Aphis sorbi Kaltenbach of recent European and American authors (but not *A. sorbi* Kaltenbach).

Aphis pyri Boyer of Gillette and Taylor (but not *A. pyri* Boyer).

Aphis kochii Schouteden of Theobald (but not *A. kochii* Schouteden).

HISTORY AND DISTRIBUTION OF THE SPECIES

The descriptions given by Koch and Kaltenbach indicate that this species was present in Europe at an early date. It now appears to be well distributed in the apple-growing regions. In America Fitch's description makes its early presence known. It would seem, however, that it was not until about 1900 that the insect assumed the importance of a leading pest. The first reports of its occurrence in injurious numbers came from the Eastern States, but in the few years following it had been observed over a wide area. At present the species occurs over nearly all the apple-growing regions of the country, and in some sections it is very abundant. In some local areas the insect may be not at all common, even though in that general region it is abundant. This seems to be due to the comparative scarcity in some places of its secondary host, and in areas where the insect assumes considerable importance plantain is usually found in great abundance. Although the species occurs abundantly in some of the Northern States, it does not seem as yet to have penetrated very far into Canada. It occurs in Quebec, Ontario, and British Columbia, but nowhere in Canada does it seem to have assumed such importance as in some sections of this country.

METHODS OF STUDY

EXPERIMENTS.—The experiments on which this paper is based were conducted along much the same line as recorded by the writers (11) for the green apple aphis. Eggs were allowed to hatch and the stem mothers and their offspring to grow on young seedlings in pots. The same methods of transfer adopted for the green aphis were employed with this species. As soon as spring migrants were produced, these were transferred to rib-grass plants grown in pots, and covered with lantern globes. In this manner the species was grown throughout the summer, and in the fall the fall migrants and males were returned to the apple. All insects possible were reared to maturity in order that the percentage of winged forms occurring throughout the summer might be ascertained. Winged forms during the summer proved to be rare and this simplified considerably the handling of the insects, since it reduced

the number of lines carried. It is quite possible that lines from stem mothers taken in different localities or possibly different rearing conditions might have resulted in a higher percentage of summer winged forms. All molts and specimens in every generation in each line were mounted for study and these many forms gave an excellent opportunity for determination of variations.

TECHNIQUE.—The technique employed for the study of insects of this species was the same as that recorded in the writers' paper (11) on the green apple aphis.

THE EGG

DESCRIPTION

Size 0.550 by 0.272 mm. The largest were 0.608 mm. long and the shortest 0.480 mm. The width varied from 0.256 to 0.288 mm. The longest eggs were not necessarily the widest. In fact, this was seldom the case.

The newly laid egg is light yellow in color, changing through greenish yellow and yellowish green to black in about four days.

LOCATION ON TREE

The eggs are laid mostly on the small twigs, under buds, or in crevices in the bark. They may, however, be laid on the small branches, or even occasionally on the large branches and trunk. They are seldom laid on the water sprouts, though this also may occur. Usually oviparous females born and reared on water sprouts lay their eggs at the base of such sprouts or on the trunk of the tree.

The small plants used in the experiments were frequently potted with portions of the highest roots exposed. In such cases some oviparous females invariably laid eggs upon these exposed roots.

HATCHING

The eggs of this species commenced hatching, in 1914, about April 8, at the same time that the eggs of *A. pomi* began to hatch, and about 10 days later than *A. avenae*. In 1915 hatching also commenced about April 8. Eggs of *A. pomi* commenced hatching on the same date. At this time the stem mothers of *A. avenae* were in the second instar.

STEM MOTHER

DESCRIPTION

FIRST INSTAR.—Morphological characters. Antennal segments as follows: III, 0.12 to 0.144 mm., average 0.133 mm.; IV, (0.048 plus 0.12 mm.) to (0.064 plus 0.136 mm.). Eyes with few facets. Cornicles short and thick, 0.088 to 0.096 mm., average 0.089 mm.

Color characters: Dark green; appendages and crown black. Insects covered after a short time with a mealy bloom.

SECOND INSTAR.—Morphological characters. Antennal segments as follows: III, 0.112 to 0.114 mm., average 0.128 mm.; IV, 0.072 to 0.096 mm., average 0.081 mm.; V, (0.064 plus 0.136 mm.) to (0.072 plus 0.168 mm.), average (0.069 plus 0.150 mm.).

Segments IV and V quite distinctly imbricated. Eyes with about 35 facets; cornicles 0.12 to 0.128 mm., average 0.123 mm., rather thick.

Color characters: Considerably lighter than specimens of the first instar, although still of a somewhat greenish shade.

THIRD INSTAR.—Morphological characters. Antennal segments as follows: III, 0.2 to 0.224 mm., average 0.213 mm.; IV, 0.096 to 0.112 mm., average 0.106 mm.; V, (0.072 plus 0.16 mm.) to (0.088 plus 0.208 mm.), average (0.08 plus 0.177 mm.). In this instar Segment III sometimes shows division, in which case Segments III and IV have about the following proportions: III, 0.144 mm.; IV, 0.112 mm. Eyes with a large number of facets; cornicles still stout and measuring 0.144 to 0.176 mm., average 0.16 mm.

Color characters: Approaching those of the adult insect.

FOURTH INSTAR.—Morphological characters. Antennal segments as follows: III, 0.192 to 0.24 mm., average 0.216 mm.; IV, 0.112 to 0.16 mm., average 0.128 mm.; V, 0.128 to 0.152 mm., average 0.136 mm.; VI, (0.08 plus 0.184 mm.) to (0.112 plus 0.24 mm.), average (0.096 plus 0.213 mm.). Cornicles 0.1224 to 0.256 mm., average 0.227 mm.

Color characters: Almost those of the adult insect.

FIFTH INSTAR.—Morphological characters. Antennal segments as follows: III, 0.336 to 0.384 mm., average 0.352 mm.; IV, 0.192 to 0.224 mm., average 0.2 mm.; V, 0.144 to 0.176 mm., average 0.16 mm.; VI, base, 0.096 to 0.112 mm., average 0.099 mm.; unguis 0 192 to 0.224 mm., average 0.208 mm. Segments imbricated, the first segment being distinctly ridged on its inner margin and armed with a number of slightly capitate hairs. Antennæ on frontal tubercles, these being armed on their inner edge with slightly capitate hairs; vertex slightly protruding; crown armed with numerous hairs and near its caudal margin with a pair of distinct tubercles (in many specimens only one of this pair present and in other specimens neither); eyes prominent, their tubercles small; prothoracic tubercles not as prominent as in the later forms; abdomen with distinct lateral tubercles and fine hairs; the last two abdominal segments each with a pair of distinct dorsal tubercles; cornicles subcylindric, 0.288 to 0.32 mm., average 0.305 mm., considerably broader at the base than at the apex, slightly flanged and strongly imbricated; cauda conical, short, densely setose and covered with numerous long hairs; anal plate rounded and similarly armed; legs with short stiff hairs, femora rough and covered with sensory-like markings, hind tibiæ 0.83 mm. long; form very globose, the abdomen not showing segmentation; length from vertex to tip of cauda 1.68 mm; width of abdomen 1.44 mm.

Color characters: General color reddish or purplish brown, dusted with a bluish white powder. Antennæ, with the exception of the basal portion of Segment III and sometimes Segment II, black; head and prothorax dark brown or blackish; abdomen varying shades of brown or purplish with a few minute dark markings which include the lateral tubercles; cauda and anal and genital plates black; cornicles black; legs entirely black with the exception of a light ring at the base of each femur; color between and surrounding the cornicles rusty.

Location: Found within the curled leaves of the apple, usually entirely hidden by the tightly rolled leaf.

LENGTH OF NYMPHAL LIFE

When newly hatched, the stem mother wanders about on the twig until a bud is reached. Here she settles and commences feeding, crowding down into the bursting bud. Before feeding she has a wrinkled appearance, but begins to fill out in a day or two.

The duration of the first instar is considerably longer than that of the following ones, but this depends a good deal on weather conditions. If

the weather is favorable, the first instar will be much shortened. The total nymphal life averaged in the experiments 15 days, and this was the average in spite of the variation in the length of the instars.

REPRODUCTION

The stem mothers began reproducing in the experiments during the 24 hours following the last molt. Considerable variation was noted amongst individuals, both as to the total number of young produced and the number produced daily. Reproduction in groups, as has been noted by the authors for *Aphis pomi*, is very common with this species also. The greatest number of young produced by any individual stem mother was 260, and these were produced during a period of 20 days. The smallest number produced by one adult was 81 in 24 days. The average number for 12 individuals was 71.1 young each, the average reproductive period being 26.3 days. The average daily production was 6.3 per insect and the greatest record was 14.6, one female giving birth to 44 young in 3 days.

LONGEVITY

The greatest length of life observed was 45 days. Many other stem mothers which died from accident before an equally long period of time were in very good condition at the time of their death. It would seem, therefore, that this period is not very far above the average.

SPRING FORMS

Several generations of aphids, in which both wingless and winged forms occur, follow the stem mother upon apple. In 1914 five apple-infesting generations occurred in the experiments, while in 1915 seven such generations were observed. In both cases the first stem-mother generation is not included in the figures given.

The first of these generations, the second generation from the egg, appears to be composed entirely of wingless insects—at least there were no winged forms in the experiments, either in 1914 or 1915. In the third generation, however, a few winged forms occurred and the percentage of winged to wingless insects increased rapidly up to the sixth generation in 1914 and the eighth in 1915, in which all the adults had wings. Two intermediates were also reared with the spring migrants.

SPRING WINGLESS VIVIPAROUS FEMALE

DESCRIPTION

FIRST INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.16 to 0.208 mm., average 0.182 mm.; IV, (0.048 plus 0.176 mm.) to (0.072 plus 0.224 mm.), average (0.059 plus 0.204 mm.). Cornicles about 0.088 mm., rather short and thick.

Color characters: General color light yellow; about the base of each cornicle a small reddish patch. Eyes dark red or brownish; cornicles dusky. Legs pale yellow with the tarsi and possibly the distal extremities of the tibiæ dusky to black. Antennæ

with the proximal half pale yellow and the distal half dusky or black. Labium pale yellow tipped with dusky brown; body somewhat pulverulent.

SECOND INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.192 to 0.232 mm., average 0.212 mm.; IV, 0.096 to 0.112 mm., average 0.104 mm.; V, (0.064 plus 0.256 mm.) to (0.08 plus 0.288 mm.), average (0.067 plus 0.272 mm.). Cornicles about 0.112 mm.

Color characters: Somewhat similar in color to the insects of the first instar, but somewhat more pinkish as compared to the distinct yellow of the first instar.

THIRD INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.208 to 0.24 mm., average 0.22 mm.; IV, 0.160 to 0.192 mm., average 0.177 mm.; V, 0.128 to 0.150 mm., average 0.14 mm.; VI, (0.064 plus 0.288 mm.) to (0.088 plus 0.384 mm.), average (0.083 plus 0.342 mm.). Cornicles 0.176 to 0.224 mm., average 0.198 mm.

Color characters: Much darker than the earlier instars, taking on the rosy tint of the adult insects and the gray slaty powdering met with on the adult.

FOURTH INSTAR.—Morphological characters. Antennæ as follows: Segment III, 0.304 to 0.4 mm., average 0.352 mm.; IV, 0.208 to 0.328 mm., average 0.271 mm.; V, 0.144 to 0.208 mm., average 0.187 mm.; VI, (0.08 plus 0.352 mm.) to (0.102 plus 0.504 mm.), average (0.094 plus 0.433 mm.). Cornicles 0.24 to 0.288 mm., average 0.259 mm.

Color characters: Similar to the previous instar, although darker and more nearly like the adult.

FIFTH INSTAR (ADULT) (Pl. 21, C).—Morphological characters. Antennæ with the following measurements: Segment III, 0.43 to 0.656 mm., average 0.52 mm.; IV, 0.256 to 0.48 mm., average 0.348 mm.; V, 0.192 to 0.288 mm., average 0.235 mm.; VI, (0.096 plus 0.4 mm.) to (0.128 plus 0.592 mm.), average (0.108 plus 0.486 mm.). Cornicles 0.336 to 0.496 mm. Body rotund; upper surface of the head often with two rather prominent tubercles and a similar pair on the dorsum of the last two abdominal segments. Cauda short, abruptly conical, setose, cornicles distinctly flanged and slightly curved, imbricated. Antennæ not distinctly imbricated, except the distal segments. Labium extending to between the second and third pairs of coxæ. Lateral tubercles distinct.

Color characters: General color rosy brown, having a pinkish cast, owing to a powdery covering. Some of the older specimens are almost of a purplish color whereas younger specimens are decidedly reddish pink. Antennæ yellowish, with the distal extremity black. Legs yellowish, the tarsi and the distal extremities of the tibiæ black or brown. Labium tipped with brown. Cornicles and eyes black.

Location: Occurring in colonies within the curled leaves of the apple.

DURATION OF NYMPHAL STAGES

The average length of nymphal life of the wingless spring form is 9 to 10 days. This period is divided about equally among the four immature stages. Occasionally one stage will be a day or even more longer than the others, and such retardation of growth may occur in any one of the four stages. These variations are apparently due almost entirely to temperature conditions, although in the experiments occasional effects were due to poor food conditions.

REPRODUCTION

Reproduction commenced almost invariably about 24 hours after the insect had attained maturity and continued for a period of from 12 to 26

days. In the experiments, with one exception to be noted later, the adults died within one or two days after depositing their last young. The average number of young deposited by 14 females was 121.8 per insect. The greatest number deposited by one female was 180 young, the smallest 66 young. It should be noted that the female which deposited only 66 young was abnormal. The average daily production for the 14 insects was 5.7 per female. The greatest daily average for one female was 14.3 young, the mother producing 43 young in 3 days. One other aphid produced 60 young in 5 days. In a general way the aphids of the earlier generations produced more young than did those which came later. No exact statement can be made, however, as there was much variation in the matter.

LONGEVITY

The average total length of life of 13 of the aphids used in obtaining the data on reproduction was 31.4 days.

As has been previously stated, all but one of the insects in question died within one or two days after depositing their last young. One insect, however, gave birth to only 66 young and then lived for 11 days more without reproducing. This aphid was killed on the eleventh day and sectioned. When killed, the insect was apparently perfectly normal, except for the fact that the abdomen was darker in color than that of the other aphids. This dark color was diffused irregularly over the abdomen and appeared to be produced by some change within the body of the insect, rather than to be simply a case of melanism in the hypodermal coloring. The insect was very plump; in fact, much plumper than were other aphids which had produced even less young.

On sectioning it was found that there was an almost complete disintegration of the reproductive system, only small isolated portions being present. Moreover, there were the remnants of two half-grown embryos lying free in the coeloma. The fat body had made an excessive growth, almost completely filling the abdomen, and being abundant in the thorax. The digestive canal was apparently perfectly normal, as were the other organs of the body.

It is very interesting to note in this connection that three examples of a similar nature were found in experiments on the life history of *Aphis avenae*.

INTERMEDIATE FORM

During the spring of 1914 two intermediates (Pl. 21, D) of this species were reared. These two insects are of particular interest since the other intermediates reared have all occurred among the summer forms, the winged insects of which migrate, if at all, to other plants of the same species as those upon which the wingless insects feed. These two insects, however, were reared in the spring upon apple. Had they become

winged they would have been unable to exist upon apple, but must have flown to plantain. Any young which they might possibly have deposited upon apple would have died soon after birth.

The two intermediates in question continued feeding upon apple after becoming adult, produced their young normally, and these, in turn, produced spring migrants, which left the apple. In other words, the two intermediates not only evince a change of form from winged toward wingless, but also a like change in habit.

In discussing the intermediates of *Aphis pomi* the writers (9) have advanced the suggestion that the winged form and bisexual reproduction represent the more primitive condition among aphids and that these insects are at present in an active state of variation toward a wingless form and parthenogenetic reproduction. If this supposition is correct, the present examples would indicate that the alternation of hosts is a more primitive condition, even possibly that the aphids were originally general feeders and that some of them are varying toward forms which will feed only upon one host.

DESCRIPTION

Morphological characters: Antennæ of about equal proportions in both specimens. Segment III, 0.576 mm.; IV, 0.352 mm.; V, 0.288 mm.; VI, base 0.112 mm.; unguis, 0.576 mm. One specimen has 6 sensoria near the distal extremity of III, 15 on IV, and 3 on V. The other specimen has both antennæ with the following sensoria: 32 and 38 on Segment III, 17 and 21 on IV, 3 and 4 on V. Cornicles in one specimen 0.4 mm. long and in the other 0.448 mm. Winged thoracic characters absent. Wings represented by small padlike structures 0.32 mm. long in one specimen and 0.16 mm. long in the other.

Color characters: General appearance and color resembling those of the wingless form.

SPRING MIGRANT

DESCRIPTION

Since the forms of the first three instars show little difference between those which become wingless and those which become winged no description is here given of the first three instars of the spring migrant.

FOURTH INSTAR (PUPA).—Morphological characters. Antennæ with the following measurements: Segment III, 0.384 to 0.432 mm., average 0.414 mm.; IV, 0.24 to 0.32 mm., average 0.28 mm.; V, 0.176 to 0.216 mm., average 0.2 mm.; VI, (0.08 plus 0.4 mm.) to (0.112 plus 0.512 mm.), average (0.96 plus 0.433 mm.). Cornicles 0.256 to 0.32 mm., average 0.272 mm.

Color characters: Thorax and wing pads pink, shaded with dusky at the tips of the pads. Top of head and first two antennal segments bluish dusky; Segments III and IV of antennæ whitish, distal segments black. Abdomen slaty blue, the embryos showing through as yellowish white patches. The covering of mealy wax gives a grayish cast to the abdomen. Between the cornicles and caudad of them a dull rusty area, not a bright rusty area as in the wingless individuals. Lateral and caudal tubercles showing as minute dark brown spots. Cornicles brownish black. Legs whitish with the exception of the tarsi and the distal tips of the tibiæ. Labium tipped with black or dark brown. Eyes dark brown.

FIFTH INSTAR (ADULT) (Pl. 20, C).—Morphological characters. Antennæ as follows: Segment I, 0.08 mm.; II, 0.064 mm.; III, 0.56 to 0.72 mm., average, 0.676 mm.; IV, 0.368 to 0.464 mm., average, 0.419 mm.; V, 0.240 to 0.32 mm., average, 0.272 mm.; VI, (0.112 plus 0.504 mm.) to (0.128 plus 0.68 mm.), average (0.116 plus 0.582 mm.). Segments I and II strongly imbricated on their inner margins and armed with a few short spines. Segment III imbricated and armed with 53 to 60 oval, double rimmed, protruding sensoria which give the segment a knotted appearance. These are distributed over the entire segment; and a number of short spinelike hairs are also present. Segment IV similar to segment III but with from 22 to 29 sensoria. Segment V also similar, but the smaller number of sensoria (4 to 10) causing the imbrications to appear more distinct. The distal sensorium on this segment is the usual fringed one and not similar to the others on the segment. Segment VI strongly imbricated throughout and with the usual sensory group at the base of the unguis. Antennæ placed on small frontal tubercles which are notched within and armed with a few capitate hairs; vertex almost straight in some specimens, while the median ocellus protrudes in others; crown with a pair of tubercles placed between the compound eyes. This character is, however, not a constant one, as the writers have many specimens in which these tubercles are lacking. Prothorax with a prominent lateral tubercle on each side. In some specimens there are two of these tubercles on one side, and in the writers' specimens this seems always to be the left side. Forewing 2.48 mm. long and 1.008 mm. wide at its broadest part. Venation usually normal, first branch of media slightly nearer its insertion than it is to the tip, radial sector considerably curved, stigma 0.56 mm. long on the costal margin; hind wing 1.6 mm. long, hamuli 0.56 mm. from the distal extremity. Abdomen with distinct lateral tubercles and with prominent dorsal tubercles on the two caudal segments; cauda short, conical, setose, and armed with usually three pairs of long curved spinelike hairs; anal plate bluntly conical or rounded, densely setose, and armed with many curved spinelike hairs. Cornicles cylindric, slightly curved, faintly imbricated and distinctly flanged; length 0.288 to 0.384 mm.; legs slender, hind tibiæ 1.07 to 1.1 mm.; hind tarsus about 0.096 mm. long.

Color characters: General color brownish green, marked with black as follows: Head above uniform black, the prothorax and the thoracic shield black, the margins, however, near the wing insertions without black markings. Abdomen with a large black quadrate patch on middle of dorsum surrounded by a narrow unmarked area; cephalad of this patch there are often a number of small transverse markings, and caudad of it a semicircular black marking which includes the insertions of the cornicles; this is sometimes fused with the quadrate patch; margins of the abdomen with three large rounded black spots cephalad of the insertion of the cornicles and with sometimes a few smaller markings, lateral margins of the thorax with a large black spot. Below marked with black as follows: Vertex, trophic tubercle, and margins and tip of labium; a small spot on the prothorax; sternal plate; a band between and encircling the hind coxæ; cauda and anal and genital plates. Antennæ black; coxæ black, trochanter and proximal extremity of femur black; remainder of femur, the distal extremity of the tibia, the tarsus, and claws black; remainder of tibia yellowish brown; cornicles black. Wings clear, veins thin, stigma dusky.

Location: Found in the curled leaves of the apple and on the leaves and stems of the plantain reproducing.

LENGTH OF NYMPHAL LIFE

The winged form requires about two days more than the wingless one for its immature stages, though this period may vary in exceptional cases from 1 to 3 days. Thus, the total length of the period is from 11 to 13 days, the usual length being 12. The two extra days are spent in the fourth or pupal stage, the pupæ being from 2 to 3 days old when the wingless form becomes adult.

REPRODUCTION

The migrants appear to commence reproduction in about 1 to 2 days after settling upon the rib grass. The period for those transferred in the experiments varied from 1 to 5 days. It is very probable, however, that those insects which required the longer period were transferred too soon after becoming winged, since in the field the migrants usually remain on the apple for one or two days at least after the last molt.

Ten migrants produced an average of 18 young, varying from 10 to 29. The average reproduction period for these individuals was 5.8 days, varying from 3 to 9 days. The daily average was 3.2 young per female. It is very interesting to note that without exception the mothers brought forth more young on the first day of reproduction than on any of the following days, the numbers of young ranging, with one or two exceptions, from 7 to 10 for that day. It will be noted later that the reproduction of fall migrants resembles that of the spring winged form.

LONGEVITY

The total average length of life for the 10 insects which have just been mentioned was 25½ days. As stated when discussing the length of life of immature forms, the period spent on apple averages 12 days, plus 1 or 2 days as adults. The average length of life on rib grass was 12½ days, varying from 3 to 29. All but two of the insects observed lived for at least 2 days after producing their last young, while one lived in this way for 15 and another for 22 days. These conditions also will be found to exist in an exaggerated form among the fall migrants.

MIGRATIONS OF THE SPECIES

For many years entomologists have recognized the importance in the life history of this species of its secondary host. The actual discovery of this host was first made by Theodore Pergande, although no record was published. It would appear that Pergande observed the aphids under greenhouse conditions, for his first date referring to the plantain is January 25, 1882. His manuscript note reads as follows: "Large numbers of this aphid are noticed to-day on leaves of the narrow-leaved plantain. * * * They are found in all stages; larva, wingless females, pupæ and winged insects." Several of the specimens referred to were mounted on slides and these have been examined by the senior writer and are without a doubt *A. malifoliae.*

Since Pergande published no account of his findings, it had been believed by entomologists that the alternate host of the species had never been located. This is the view set forth in all the publications on the species. Ross (8, p. 23), however, reported his transfers made to *Plantago major* and *P. lanceolata;* and since his note appeared, these plants have become fairly well known as the alternate hosts of the species. The writers' observations on the species in connection with plantains were begun in 1913 when the senior writer made transfers to

broad-leaved plantain. Other transfers were made during 1914, but it was not until the spring of 1915 that a large and definite migration to plantains was noted in the field. Winged specimens were then observed alighting in numbers and reproducing upon the underside of the leaves and on the long flower stems of the rib grass (Pl. 23). Ross (8) reported that he was able to rear the species throughout the summer on apple. This the writers were unable to do even with a very few insects on a plant; all of the lines carried ultimately produced winged forms and migrated. It must be remembered also in this connection that the writers selected wingless and winged forms from each mother in order to obtain offspring. It is quite possible, however, that the lines carried by Ross had less of a tendency toward winged forms throughout than had those of the writers. Since the migration does not occur in any definite generation but is scattered throughout the apple life of the insect from the second generation onward, such a condition of affairs might easily occur. The following fact also is of importance here: The intermediates discovered by the writers remained upon apple and there reproduced, thus taking on the nature of the primary wingless forms. This would indicate that ultimately the species may become a permanent apple species like *Aphis pomi*, and the fact that Ross had carried it through the season upon apple would seem to show that this tendency is further advanced in the Ontario region where Ross conducted his experiments than in the Virginia region where the writers reared their insects.

The fact that spring migrants occurred in every generation on apple in the writers' experiments from the third to the eighth caused this migration to spread over a long period of time, from May 20 to July 1 at Vienna, Va. The pupæ of the spring migrants very often do not feed but may be found under loose bark and in the crevices of the limbs and trunk. Many, however, remain within the curled leaves. In these places the winged form is produced and in a few days it migrates to the rib grass and settles upon the underside of the leaves and on the flower stems. Here it produces its young. Occasionally some winged forms reproduce upon the broad-leaved plantain, but at Vienna this is rare as compared to the large number that migrate to the rib grass.

The fall migrants leave the plantains about 1 or 2 days after becoming adult, and fly to apple trees, where they settle upon the under surfaces of the leaves and commence feeding. Reproduction usually begins within 24 hours after the insect reaches the apple, though the migrants may feed for two or three days before producing young.

When mature, the males leave the plantain, flying to apple. If the oviparous females are not fully mature when the males arrive, the latter settle down beside them and feed until such time as copulation can take place.

Recently, since this paper was prepared, Brittain (12, p. 16, fig. 2) has reported his generation experiments on plantain.

SUMMER FORMS

The usual summer form of this species is wingless. In fact, among over 1,000 individuals reared to maturity during the summer only 6 specimens of the winged form were observed. One of these died when a pupa. This latter insect belonged to the sixth generation from the spring migrant. The other 5 insects were apparently members of the third generation on plantain, although this was ascertained with certainty for only one individual, the other form occurring in experiments which had been set aside merely to maintain a surplus stock of material. Only 2 of these winged insects reproduced, their progeny being normal summer wingless aphids. Thus, while the winged insects may occur on plantain they are of no particular importance in the life history of the species.

It should be noted in connection with this form that many wingless insects were reared on the plants in the generations with these winged aphids and in the generations preceding and following them, the ratio being over 100 to 1. The production of this form can hardly have been due, therefore, to food conditions.

A maximum of 14 generations of the summer form were reared on plantain, with a possible theoretical minimum of 4 generations.

SUMMER WINGLESS VIVIPAROUS FEMALE

DESCRIPTION

FIRST INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.176 to 0.224 mm., average 0.196 mm.; IV, (0.048 plus 0.208 mm.) to (0.064 plus 0.248 mm.), average (0.056 plus 0.238 mm.). Cornicles 0.08 to 0.096 mm., average 0.084 mm.

Color characters: Pale greenish yellow with ultimately a rusty color across the abdomen between the cornicles. The color sometimes extends into the cornicles.

SECOND INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.16 to 0.24 mm., average 0.209 mm.; IV, 0.102 to 0.128 mm., average 0.107 mm.; V, (0.064 plus 0.24 mm.) to (0.072 plus 0.32 mm.), average (0.065 plus 0.288 mm.). Cornicles 0.112 to 0.144 mm., average 0.136 mm.

Color characters: Similar to the specimens of the first instar.

THIRD INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.128 to 0.176 mm., average 0.164 mm.; IV, 0.128 to 0.184 mm., average 0.156 mm.; V, 0.128 to 0.144 mm., average 0.136 mm.; VI, (0.064 plus 0.288 mm.) to (0.088 plus 0.392 mm.), average (0.076 plus 0.342 mm.). Cornicles 0.0176 to 0.208 mm., average 0.19 mm.

Color characters: Similar to those of the second instar.

FOURTH INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.24 to 0.288 mm., average 0.264 mm.; IV, 0.176 to 0.24 mm., average 0.201 mm.; V, 0.144 to 0.192 mm., average 0.166 mm.; VI, (0.08 plus 0.36 mm.) to (0.096 plus 0.424 mm.), average (0.086 plus 0.39 mm.). Cornicles 0.24 to 0.272 mm., average 0.265 mm.

Color characters: The same as those of the adult form.

FIFTH INSTAR (ADULT) (Pl. 22, A).—Morphological characters. Antennæ slender, extending beyond the tips of the cornicles; measurements as follows: Segment III, 0.416 to 0.512 mm., average 0.454 mm.; IV, 0.256 to 0.368 mm., average 0.305 mm.;

V, 0.192 to 0.256 mm., average 0.225 mm.; VI, (0.088 plus 0.368 mm.) to (0.112 plus 0.512 mm.), average (0.097 to 0.441 mm.); segments imbricated, armed with a few hairs, but without sensoria. Antennal tubercles distinct; head without dorsal tubercles met with in the wingless form from apple. Legs slender; hind tibia 0.656 to 0.784 mm. long. Cornicles very slender, slightly curved, distinctly flanged and imbricated; length, 0.384 to 0.464 mm., average 0.443 mm. Abdomen without the prominent caudal tubercles met with in the apple form; cauda conical, rather elongate, more slender than that of the apple form, armed with three pairs of hairs and imbricated by rows of minute setæ. Form more elongate than the spring wingless forms, 1.36 by 0.8 mm.

Color characters: Color creamy-yellow with a slight brownish or even purplish cast; eyes dark brown; distal portions of antennæ, tips of cornicles, tip of labium, and tarsi brown or dusky. Between the cornicles and inclosing their insertions is a band of rusty red, this color sometimes also extending into the proximal portion of the cornicles; the red eyes of the embryos showing through the abdomen of the adult.

Location: Found in colonies on the under surface of the leaves of rib grass (*Plantago lanceolata*) and also on the flower stems; rarely also on other species of the genus.

DURATION OF NYMPHAL STAGES

This form of the species became adult in from 8 to 12 days, the period varying with the prevailing temperature. Insects born from the 10th to the 20th of June required 10 days for this period, while those born in July matured in 8 to 9 days. Later the period increased again to 12 days in September.

REPRODUCTION

The average number of young produced by 35 adults was 65.2, the maximum being 108 (produced by two insects) and the minimum 12. The average length of the reproductive period was 19 days, thus varying from 5 to 35 days. The average daily production of these 35 adults was 3.4 young per mother. The greatest average daily production for one adult was 5.4, this insect producing 43 young in 8 days; the lowest was 2.2, 77 young in 35 days. One insect brought forth 14 young in one day while 8 produced 10 or more in a like period. Of the two winged insects which reproduced, one brought forth 21 young in 7 days, and the other 13 young in 3 days. The first of the two lived for a few days after reproduction ceased.

LONGEVITY

The average total length of life for this form was 28 days, varying from 14 to 45 days. In general the insects born during the early part of the summer, particularly in June, were longer lived than any which followed, the latter all equaling or exceeding the average for the entire summer.

SUMMER WINGED VIVIPAROUS FEMALE

The early instars of this form are very similar to those of the summer wingless viviparous female and those of the fall migrant. A description of the fifth instar (adult) only will be given here. Since the form was

of very rare occurrence throughout the summer, it is not worth while to give averages for these very few insects.

FIFTH INSTAR (ADULT).—Morphological characters. Antennæ with the following measurements: Segment III, 0.688 mm.; IV, 0.496 mm.; V, 0.304 mm.; VI (0.128 plus 0.648 mm.). Cornicles 0.352 mm. Segment III with about 58 circular sensoria, IV with 34 similar ones, V with 6 or 8 arranged evenly along the segment. Head with tubercles above and the last two segments of the abdomen with a pair of dorsal tubercles.

Color characters: Similar to those of the spring migrant, the abdomen above nearly uniform brownish black or with a distinct patch.

DIMORPHIC REPRODUCTION

The writers have already noted in two other species of aphids, *A. pomi* and *A. avenae*, that the late summer and early fall individuals of the summer form may produce two forms of young. In *A. malifoliae* both summer wingless and fall migrants, or fall migrants and males, may be produced by one mother. In the experiments the former combination occurred, in a general way, earlier than did the latter. Records of the production of all three forms by one mother were not obtained.

As we found to be the case with *A. avenae*, when one mother produced both fall migrants and males, the latter were usually her last progeny.

FALL FORMS

Among the fall forms may be included the fall migrant which leaves the plantains and flies to apple, the oviparous females which are deposited upon the apple leaves by these fall migrants, and the males which fly from the plantains to fertilize the oviparous females.

FALL MIGRANT

DESCRIPTION

The early instars of the fall migrant are practically the same as those of the summer wingless form. It is therefore unnecessary to give descriptions of any instars excepting those following:

FOURTH INSTAR (PUPA).—Morphological characters. Antennæ with the following measurements: Segment III, 0.4 to 0.464 mm., average 0.427 mm.; IV, 0.288 to 0.344 mm., average 0.315 mm.; V, 0.208 to 0.24 mm., average 0.227 mm.; VI, (0.096 plus 0.488 mm.) to (0.112 plus 0.56 mm.), average (0.107 plus 0.518 mm.). Cornicles 0.288 to 0.320 mm., average 0.305 mm.

Color characters: Similar to the pupæ of the spring migrant.

FIFTH INSTAR (ADULT) (Pl. 21, A).—Morphological characters. Antennæ with the following measurements: Segment III, 0.624 to 0.800 mm., average 0.689 mm.; IV, 0.376 to 0.528 mm., average 0.472 mm.; V, 0.256 to 0.336 mm., average 0.308 mm.; VI, (0.112 plus 0.56 mm.) to (0.152 plus 0.712 mm.), average (0.132 plus 0.632 mm.). Segment III with about 60 circular elevated sensoria, IV with about 27, V with about 6 sensoria. Head without tubercles above as is usual in the spring migrant. Prothorax with very small lateral tubercles. Abdomen also with very small ones. Cornicles 0.304 to 0.384 mm., average 0.348 mm. Cauda conical, short; last two segments of the abdomen without tubercles above as in the spring migrant. Otherwise as in that form.

Color characters: Similar to those of the spring migrant. Abdomen usually with one large central black patch, three or four marginal patches, and a transverse band caudad of the cornicles, this band extending cephalad at its edges to touch the base of the cornicles. In some specimens the whole of the abdomen appears a uniform black and the legs also do not show the yellow regions usually met with.

Location: Upon the leaves of the plantain, usually upon the underside, and upon the underside of the leaves of the apple, depositing young oviparous females.

LENGTH OF NYMPHAL PERIOD

The length of the nymphal period varied from 13 or 14 days in early September to as much as 24 days for aphids born in October. The average period was 16 to 18 days. No figures for the various instars can be given since they varied greatly with the temperature, so that, while in one case the first instar might be the longest, in others the third or fourth would be.

REPRODUCTION

Sixteen fall migrants produced 114 young, an average of 7.1 young per mother. The greatest number produced by one mother was 13 (or more), two insects together producing 25; the smallest number was 3. The average length of the reproductive period of 25 insects was 5 days, varying from 1 to 10 days. In every case all but one or two of the young were produced within a period of 1 to at most 2 days. Later at periods varying from 3 to 8 days one or two more young might be produced.

LONGEVITY

The adults of this form usually lived for a considerable period after reproduction ceased, this period varying from 2 to (in one case) over 40 days.[1] The average length of this post-reproductive period for 15 insects was 23.6 days.

The longest total life recorded was 62 days, while the average was about 45 days.

The conditions with regard to the rate of oviposition found to exist among both spring and fall migrants are very interesting, since they are the exact opposite of the theoretical conditions for insects. The general statement is commonly made that those females which produce all their eggs (or progeny) in a short period die very soon afterwards, while the females which live for a long time are those which produce only a few eggs (or young) daily. In this case, however, the adults produce their young in a short period and then proceed to live for many days. The theory is based, in part at least, on the proposition that the insects which produce all their offspring or progeny within a short period become exhausted, and, of course, with these migrants only a small number of young are produced. Still, in so far as the general theory endeavors to explain the causes of a long adult life, it fails for these forms.

[1] Experiment closed before insect died.

MALE

DESCRIPTION

As with the fall migrant, the earlier instars of the male are similar to those of the wingless viviparous form; only the fourth and fifth instars, therefore, are here described.

FOURTH INSTAR (PUPA).—Morphological characters. Antennæ with the following measurements: Segment III, 0.416 mm.; IV, 0.32 mm.; V, 0.216 mm.; VI, (0.092 plus 0.504 mm.). Segment III with about 58 sensoria, IV with about 27, V with about 7. Cornicles about 0.284 mm.

Color characters: Somewhat similar to those of the spring pupa.

FIFTH INSTAR (ADULT) (Pl. 21, B).—Morphological characters. Antennæ with the following average measurements: Segment III, 0.728 mm.; IV, 0.462 mm.; V, 0.302 mm.; VI, (0.113 plus 0.657 mm.). Cornicles 0.304 mm., slightly thicker than those of the migrants. Head without tubercles above, prothorax with very minute lateral tubercles, sometimes with none visible; lateral abdominal tubercles very small; last two segments of abdomen without tubercles above as in the spring migrant. In this respect the male is like the fall migrant.

Color characters: Similar to those of the fall migrant. In many cases the large central abdominal spot is broken into a number of irregular bands and the crossband caudad of the cornicles is often divided, the total forming a series of cross stripes on the abdomen.

PRODUCTION

As has been noted previously, the males, when produced by a mother also bearing fall migrants, were usually the last progeny of the mother. The few mothers which produced only males were sisters of fall migrants. In this way the production of males commenced at about the same time as did that of the oviparous females.

NYMPHAL STAGES

The period spent in the immature stages varied from about 20 to 25 days. No general statement can be made as to the duration of the various instars, since these varied greatly among the individual insects.

MIGRATION

When mature, the males leave the plantain, flying to apple. If the oviparous females are not fully mature the males usually settle down beside them and feed.

OVIPAROUS FEMALE

DESCRIPTION

FIRST INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.144 to 0.16 mm., average 0.148 mm.; IV, (0.048 plus 0.184 mm.) to (0.056 plus 0.216 mm.), average (0.049 plus 0.196 mm.). Cornicles 0.056 mm.

Color characters: Very pale greenish yellow with brown eyes.

SECOND INSTAR.—Morphological characters. Antennæ with the following measurements: Segment III, 0.136 to 0.16 mm., average 0.142 mm.; IV, 0.064 to 0.08 mm., average 0.07 mm.; V, (0.056 plus 0.216 mm.) to (0.064 plus 0.248 mm.), average (0.059 plus 0.232 mm.). Cornicles 0.08 mm.

Color characters: Slightly darker than in the first instar.

THIRD INSTAR.—Morphological characters. Antennæ with the following measurements. Segment III, 0.192 to 0.224 mm., average 0.206 mm.; IV, 0.088 to 0.104 mm., average 0.096 mm.; V, (0.064 plus 0.264 mm.) to (0.072 plus 0.296 mm.), average (0.065 plus 0.273 mm.). Cornicles 0.112 mm.

Color characters: Somewhat more orange-yellow than the earlier instars, with more or less distinct brownish areas about the bases of the cornicles.

FOURTH INSTAR.—Morphological characters. Antennæ with the following measurements. Segment III, 0.144 to 0.184 mm., average 0.169 mm.; IV, 0.112 to 0.144 mm., average 0.128 mm.; V, 0.112 to 0.128 mm., average 0.12 mm.; VI, (0.064 plus 0.296 mm.) to (0.08 plus 0.344 mm.), average (0.075 plus 0.31 mm.). Cornicles 0.144 mm.

Color characters: General color yellow-orange, with brownish red patches around the bases of the cornicles; head grayish, eyes brown to black.

FIFTH INSTAR, ADULT (Pl. 22, B).—Morphological characters. Antennæ with the following measurements: Segment III, 0.208 to 0.256 mm., average 0.241 mm.; IV, 0.152 to 0.192 mm., average 0.169 mm.; V, 0.128 to 0.16 mm., average 0.142 mm.; VI, (0.08 plus 0.304 mm.) to (0.088 plus 0.36 mm.), average (0.081 plus 0.329 mm.). Cornicles 0.192 to 0.216, average 0.204 mm. Antennæ without sensoria. Head occasionally with a pair of tubercles above but the last two segments of the abdomen without such tubercles. Cauda short and abruptly conical.

Color characters: Similar to those given for the previous instar excepting that the colors are a little more distinct. The eggs show through the body as dark areas.

Location: Found on the underside of the apple leaves feeding, or on the twigs or in the axils of the buds depositing eggs.

NYMPHAL STAGES

The oviparous females required a period of from 20 to about 28 days for the immature stages. As with the males, the duration of the various instars varied greatly with the individuals, the principal cause of this being the variation of the prevailing temperatures.

MATING

Mating occurred mostly on the twigs. Males mated with several females and in some cases the oviparous females mated at least twice. As was the case with *A. avenae*, the male endeavors to copulate with every adult oviparous female he meets; and unless the female has just mated, she does not endeavor to hinder the male.

OVIPOSITION

Nineteen ovipara laid a total of 120 eggs, an average of 6.3 eggs per insect. Five of these oviparous females laid 36 eggs, an average of a little over 7 eggs each. The highest record for one oviparous female is, therefore, 8 eggs.

FEEDING HABITS

The results of the feeding of the rosy aphis are very noticeable, as the leaves are much curled thereby. (Pl. 24, B.) The young stem mothers crowd into the opening buds, and as the leaves grow they curl and twist about the insects. As young are produced these reach other leaves and

soon there is a large cluster of twisted leaves which is very conspicuous. In orchards composed of large trees these curled bunches are usually met with on the lower half of the trees and very often the small fruit spurs on the larger limbs in the body of the tree are affected. On very young trees, however, the feeding habits seem to differ in that the growing tips of the branches are attacked. This causes them, as they develop, to become twisted (Pl. 25, B), and as this growth hardens the limb is permanently deformed by being looped upon itself (Pl. 25, C). A branch will sometimes become looped several times, thus causing a much deformed tree unless the affected branches are cut out. In very young trees that are badly infested this is often a good portion of the tree.

The insects may also be found feeding upon the fruit, and this they cause to be reduced in size, irregular in shape, and somewhat gnarled, or more or less pitted (Pl. 25, A, D). In orchards composed of large trees this damage to the fruit is often a factor of considerable importance.

As has already been stated, the normal summer host of the species appears to be rib grass. During the season of 1915, however, the insects were reared successfully on broad-leaved plantain (*Plantago major*) for a period of two months. No record of the generations was kept in this case and no transfers were made. The plant finally died. At that time a strong healthy colony was living upon it and apparently under normal conditions would have survived until fall. In several other experiments, however, much difficulty was experienced in procuring successful transfers from the apple to this species of plantain. Rib grass appears to be the host preferred. This is borne out by an examination of the occurrence of the insects in orchard regions. Observations were made over a large extent of orchard territory. Wherever the rosy aphis was found to be very abundant the narrow-leaved plantain was common in and about the orchards, the worst infested orchards being full of the growing plantain.

The writers' observations upon the insects, both in the experiments and in the field, indicate that all parts of the rib grass are subject to attack. The insects appear to feed with equal readiness upon the leaves, the stem, and the flower stalks, and they may be found upon both sides of the leaves. The greater number of the insects, however, fed on the under surface of the leaves, especially along the veins.

In the fall the migrants alight on the underside of the apple leaves, and when the oviparous females are produced these feed also upon the underside of the leaves. The males, after migration from the plantains, often may be found feeding with immature oviparous forms. So far as the writers have been able to observe, these fall forms do not cause the leaves to curl and twist as do the spring forms.

SUMMARY OF LIFE HISTORY

The eggs of this species begin hatching early in April (about April 8 in 1915) and hatching ceases in about a week (April 16 in 1915). The first stem mothers begin reproduction about April 25. From 5 to 7 generations of the spring forms occur on apple in Virginia, although Ross reports the species all summer on apple in Ontario. The first generation is wingless. A few winged forms appear in the next generation and their percentage to the wingless insects increases steadily in each generation until finally all the insects produced become winged. Intermediates may also occur, these acquiring the wingless habits and behaving like wingless insects.

Migration to plantain commences about May 20, and most of the insects have left the apple by about June 20. A few may continue on apple till about July 1.

From 4 to 14 generations of the summer form occur at Vienna, Va. These insects are practically all wingless, only a few occasional winged insects appearing.

The first fall migrants become adult about the second week of September (Sept. 13 in 1915; these insects were born on Aug. 31). They remain on the trees until after November 1. (In the writers' experiments they were produced till a much later period, but in the field they succumb to prevailing low temperatures more quickly than do either oviparous females or males.)

Production of oviparous females commences about the middle to the 20th of September, but very few are produced till early in October and their production is at its height about the middle of that month. Males begin to appear early in October, at the time the oviparous females begin to become adults, and the males also are most numerous about the last of October and early in November.

Oviposition commences the middle of October and continues till the oviparous females are all dead. Some oviparous females may oviposit as late as the latter part of December in case excessive low temperatures have not occurred before that time.

The life history as summarized is for the vicinity of Washington, D. C.

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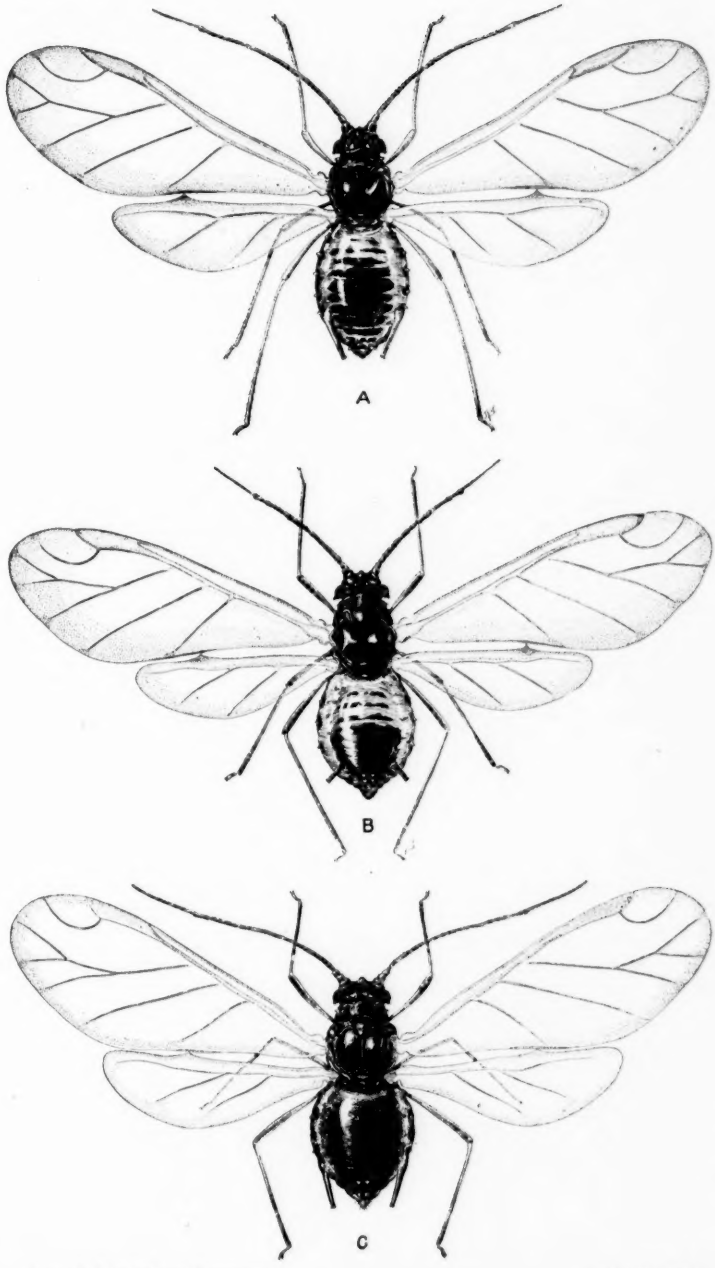
PLATE 20

A.—*Aphis sorbi:* Spring migrant.
B.—*Aphis kochii:* Spring migrant.
C.—*Aphis malifoliae:* Spring migrant.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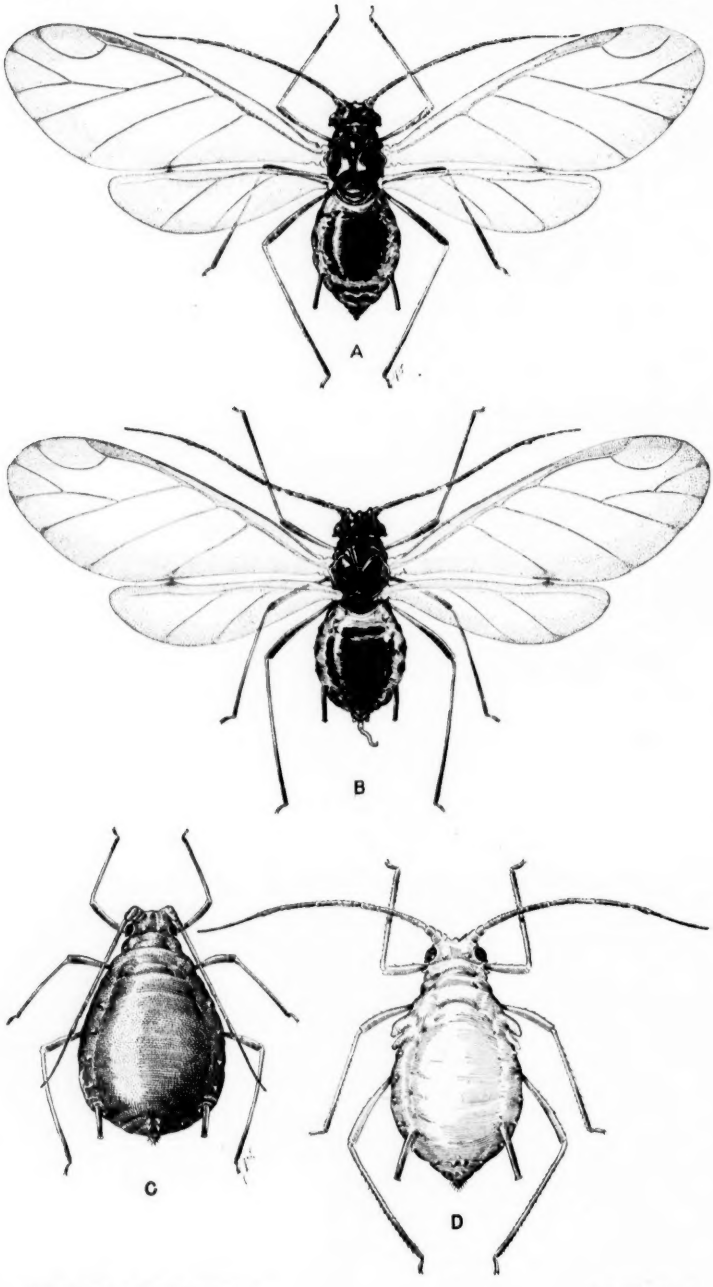
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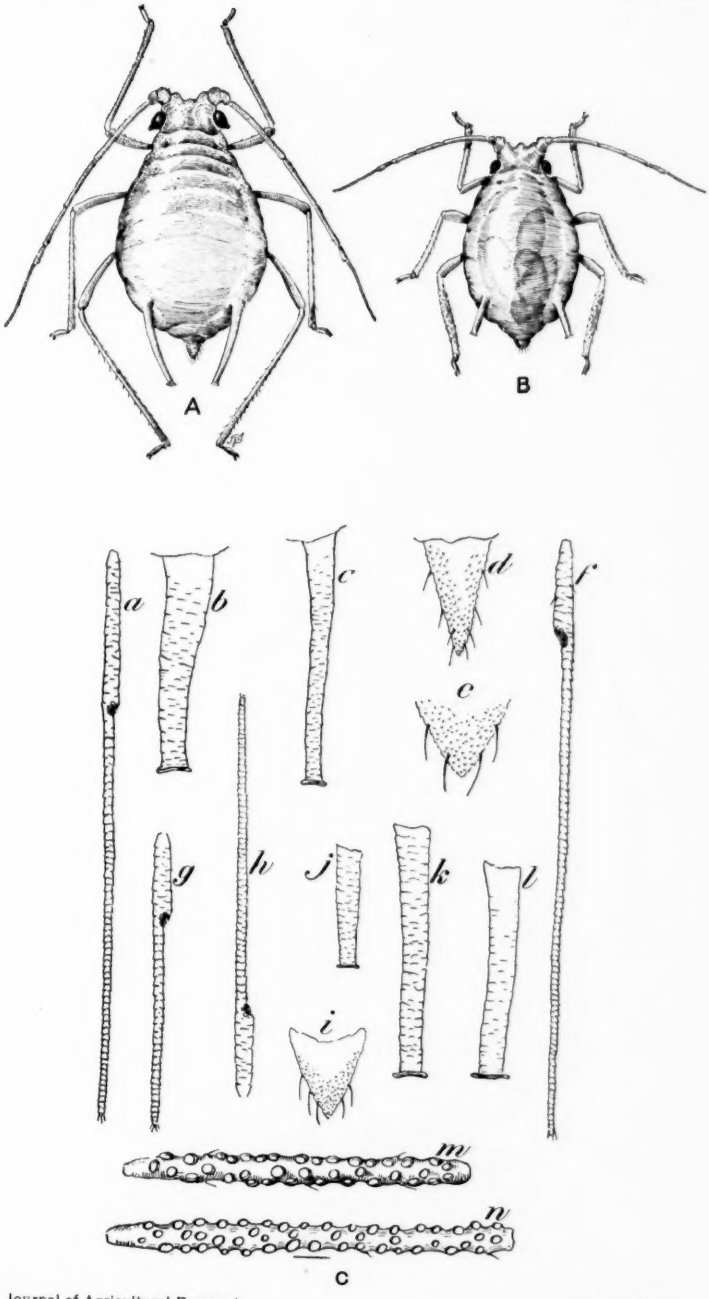
PLATE 21

Aphis malifoliae:

A.—Fall migrant.
B.—Male.
C.—Spring wingless female.
D.—Intermediate form.

PLATE 22

A.—*Aphis malifoliae:* Summer wingless form.
B.—*Aphis malifoliae:* Oviparous female.
C.—Structural details of *Aphis malifoliae*, *A. sorbi*, and *A. kochii*.
a, *A. sorbi:* Segment VI of antenna of winged form.
b, *A. malifoliae:* Cornicle of spring wingless form.
c, *A. malifoliae:* Cornicle of summer wingless form.
d, *A. malifoliae:* Cauda of summer wingless form.
e, *A. malifoliae:* Cauda of spring wingless form.
f, *A. malifoliae:* Segment VI of antenna of winged form.
g, *A. malifoliae:* Segment VI of antenna of stem mother.
h, *A. kochii:* Segment VI of antenna of winged form.
i, *A. sorbi:* Cauda of winged form.
j, *A. kochii:* Cornicle of spring migrant.
k, *A. sorbi:* Cornicle of spring migrant.
l, *A. malifoliae:* Cornicle of spring migrant.
m, *A. sorbi:* Segment III of antenna of spring migrant.
n, *A. malifoliae:* Segment III of antenna of spring migrant.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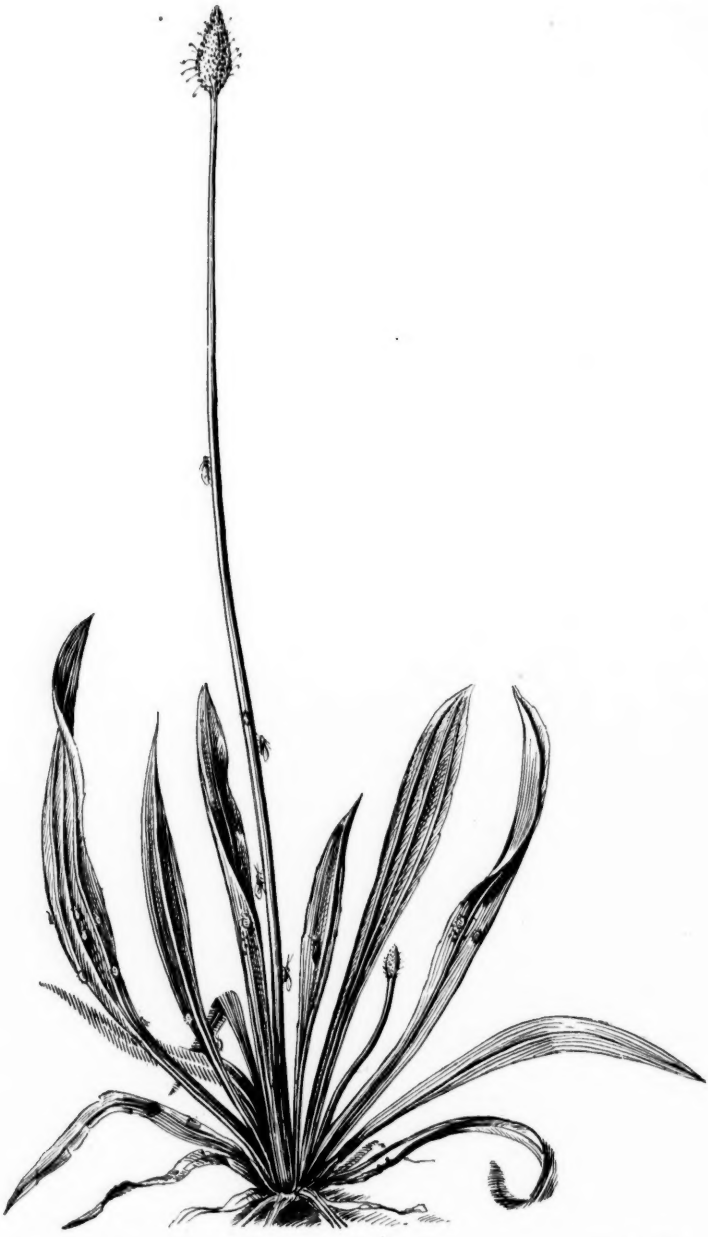

PLATE 23

Aphis malifoliae on its alternate host, *Plantago lanceolata*.

PLATE 24

A.—Broad-leaved plantain showing the effect of an attack by *Myzus plantaginis*.
B.—Apple leaves curled by colonies of *Aphis malifoliae*.

A

B

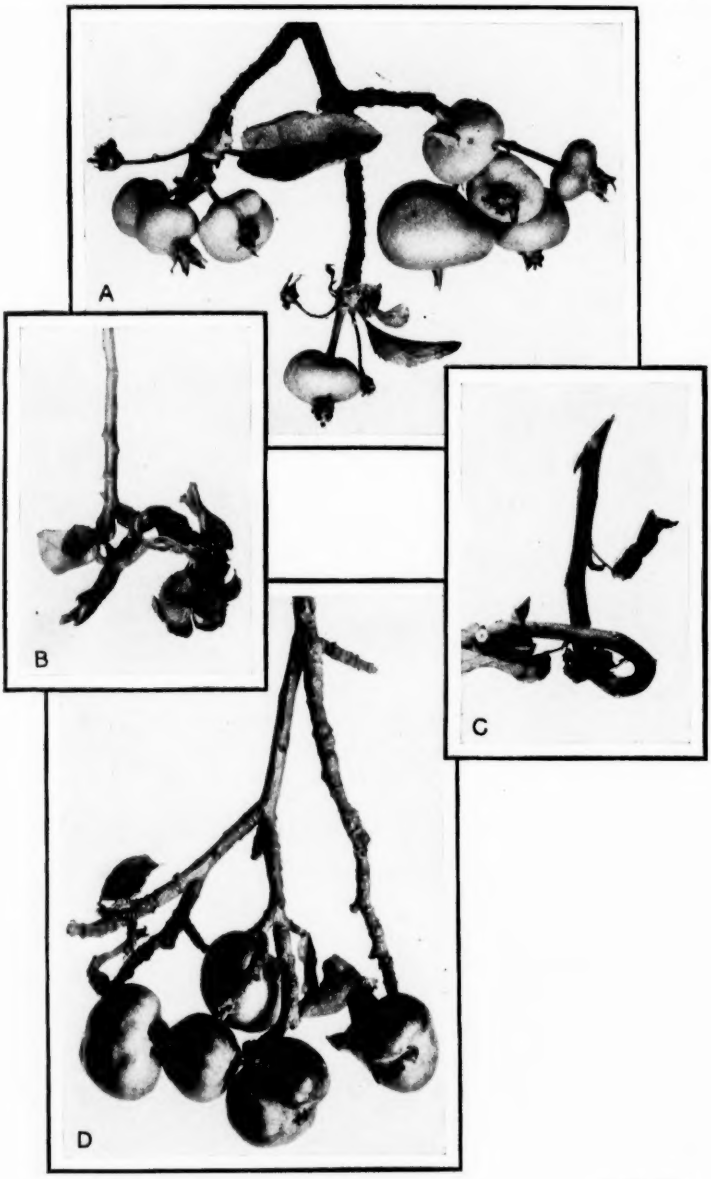
A
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PLATE 25

A.—Rhode Island Greening apples deformed by *Aphis malifoliae.*
B.—Apple twigs twisted by colonies of *Aphis malifoliae:* Beginning of twisting.
C.—Apple twigs twisted by colonies of *Aphis malifoliae:* Twisted twig.
D.—Winesap apples deformed by *Aphis malifoliae.*

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